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WYOMING

ENGINEERING HANDBOOK

for

Work Unit Staffs

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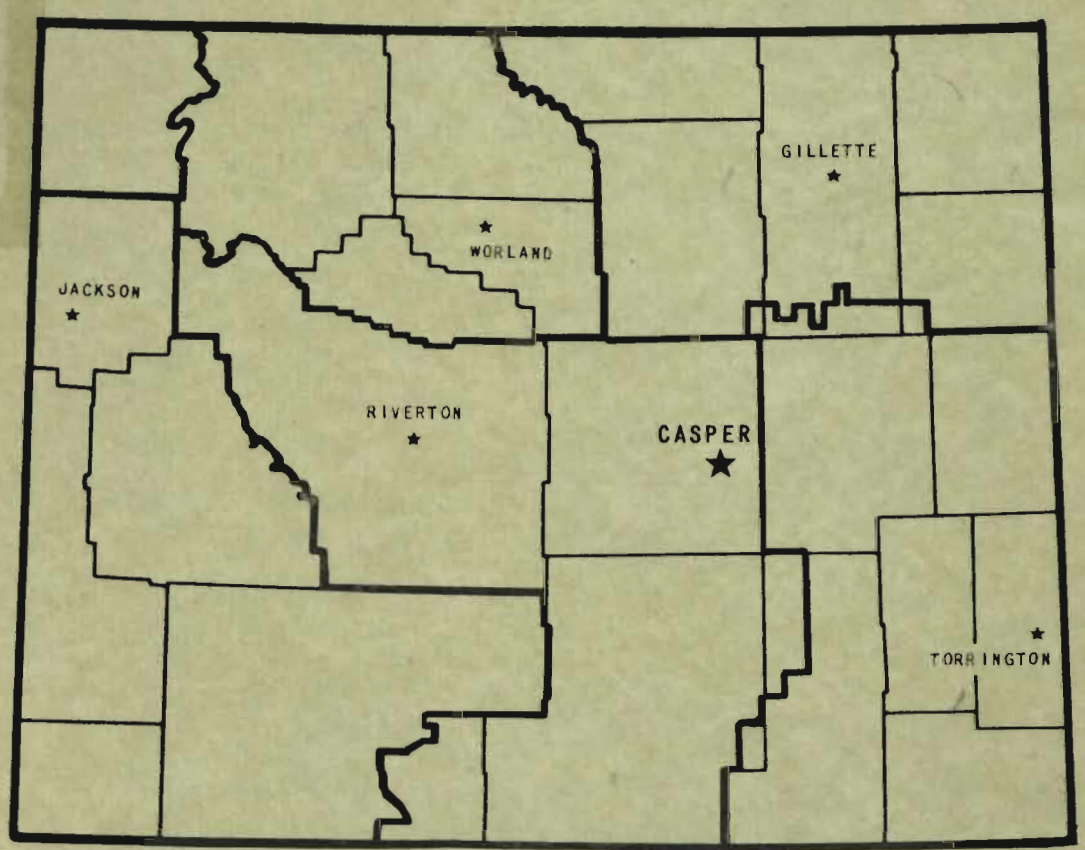


U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
CASPER, WYOMING

WYLDCAT

Wyoming Engineering Handbook for Work Unit Staffs
- Soil Conservation Service -

Table of Contents

Handbook

1 - Surveying
2 - Data Sheets
3 - Estimating Runoff
4 - Terracing
5 - Vegetated Outlets and Waterways
6 - Diversion Ditches
7 - Drainage
8 - Irrigation
9 - Earth Dams and Dugouts
10 - Spring Development and Hydraulic Rams
11 - Wells and Pumps
12 - Grade Stabilization
13 - Stream Bank Protection
14 - Water Spreading
15 - Structures
16 - Hydraulics
17 - Contour Farming and Contour Strip Cropping
18 - Contour Furrows and Pitting on Pasture and Range Land
[19 - missing]
20 - Concrete

Appendix 1 - Earthwork and Hydraulic Tables

Appendix 2 - Standard Structural Plans

CONTENTS

PART 1

SURVEYING

Subject	Page
1. General	1-1
Introduction	1-1
Purpose	1-1
Scope	1-1
Definition	1-2
Level Surface	1-2
Horizontal Plane	1-2
Horizontal Line	1-2
Horizontal Angle	1-2
Vertical Line	1-2
Vertical Plane	1-2
Vertical Angle	1-2
Horizontal distances	1-2
Elevation of a point	1-3
Difference in elevation	1-3
2. Surveying Equipment	1-3
Engineer's transit	1-3
Engineer's level	1-3
Range pole, flag pole, or flag	1-6
Tapes or chains	1-6
Chaining pins or Arrows	1-6
Level Rod	1-6
Stadia Rod	1-6
Target	1-6
Plane Table and Alidade	1-6
Hand Level	1-6
Abney Level or Clinometer	1-10
Planimeter	1-11
3. Surveying Terms	1-11
Chaining	1-11
Flagman	1-11
Rodman	1-11
Back sight	1-11
Foresight	1-12
Hub	1-12
Line	1-12
Turning Point	1-12
Bench Mark	1-12

4. Hand Signals 1-12

5. Measurement of Horizontal Distances 1-15

Pacing ---------- 1-15
Chaining ---------- 1-15
Stadia ---------- 1-18

6. Care of Equipment 1-18

Transportation and Storage ---------- 1-18
Field Care ---------- 1-19

7. Setting up Instruments 1-20

Engineers Level ---------- 1-20
Engineers Transit ---------- 1-21
Measuring horizontal angles ---------- 1-23
Measuring vertical angles ---------- 1-24
Plane Table and Telescopic Alidade ---------- 1-24

8. Cleaning, Inspecting and Lubricating Instruments 1-27

Clamps that Bind ---------- 1-28
Seizure of Limb and Verniers ---------- 1-28
Spindles and Sockets ---------- 1-28
Lenses ---------- 1-29
Axle Bearings ---------- 1-29
Binding or Freezing ---------- 1-29
Graduations ---------- 1-29
Leveling Screws ---------- 1-29
Tripods, rods and tapes ---------- 1-29
Repair ---------- 1-29

9. Adjustment of Instruments 1-30

Adjustment of the Transit ---------- 1-30
Plate Bubbles ---------- 1-31
Vertical Cross Hair ---------- 1-31
Horizontal Cross Hair ---------- 1-32
Standards ---------- 1-33
Telescope Bubble ---------- 1-34
Adjustment of the Level ---------- 1-34
Wye Level ---------- 1-36
Dumpy Level ---------- 1-39
Hand Level ---------- 1-40
Adjustment of the Plane Table Alidade ---------- 1-40

10. Survey Field Notes 1-42

Form ---------- 1-42
Indexing ---------- 1-43

11. Types of Surveys 1-43

Differential Leveling ---------- 1-43
Procedure ---------- 1-44
Precision ---------- 1-48
Profiles and Cross Sections ---------- 1-49
Vertical Curves ---------- 1-58
Traverse or Route Surveys ---------- 1-61
Procedure ---------- 1-62
Deflection Angle Traverse ---------- 1-63
Circular Curves ---------- 1-67
Transit Stadia Traverse (Elevation not required) --------- 1-71
Transit Stadia Traverse (Elevation required) ---------- 1-78
Topographic Surveys ---------- 1-79
Grid Survey ---------- 1-79
Setting Stakes ---------- 1-82
Plus Stakes ---------- 1-83
Bench ---------- 1-86
Taking Elevations at Grid Points ---------- 1-86
Land Leveling Grids ---------- 1-86
Plane Table Survey ---------- 1-87
Beaman Stadia Arc ---------- 1-87
1st Column - Distance ---------- 1-91
2nd Column - Arc ---------- 1-91
3rd Column - Product ---------- 1-91
4th Column - Rod ---------- 1-94
5th Column - Difference of Elevation ---------- 1-94
6th and 7th Column - Elevation of H.I. ---------- 1-94
Slope Staking ---------- 1-95

12. Examples of Surveys for Conservation Structures 1-102

Stock Water Dams ---------- 1-102
Grade Stabilization Structures ---------- 1-104
Large Open Ditch Surface Drains ---------- 1-107
Small Farm Surface Drains ---------- 1-112
Layout Surveys for Structures ---------- 1-117

13. Land Surveys (General) 1-119

Scheme of Subdivision ---------- 1-119

LIST OF FIGURES

PART 1

SURVEYS

Figure Number	Title	Page
1.1	Engineer's Transit	1-4
1.2	Wye Level	1-5
1.3	Range Poles	1-7
1.4	Tapes or Chains	1-7
1.5	Chaining Pin or Arrow & Steel Carrying Ring for Arrows	1-8
1.6	Stadia Rods & Leveling Rods with Target	1-8
1.7	Alidade & Plane Table Tripod	1-9
1.8	Abney Level and Hand Level	1-10
1.9	Planimeter	1-11
1.10	Code of Hand Signals	1-13
1.11	Code of Hand Signals (numbers)	1-14
1.12	Breaking Chain	1-17
1.13	One Minute Vernier set at 0°	1-23
1.14	One Minute Vernier	1-23
1.15	Locating a point on Plane Table	1-25
1.16	Solution of Triangle of Error (Plane Table)	1-26
1.17	Solution of Triangle of Error (Plane Table)	1-26
1.18	Adjustment of the Plate Bubbles	1-31
1.19	Adjustment of the Cross-Hairs	1-31
1.20	Adjustment of the Cross-Hairs (2nd Part)	1-32
1.21	Adjustment of the Standards	1-33
1.22	Adjustment of Level (Two Peg Method)	1-35
1.23	Adjustment of the Cross Hairs (2nd Part)	1-37
1.24	Adjustment of the Bubble Tube by Indirect Method	1-38
1.25	Adjustment of the Wyes	1-39
1.26	Method Differential Leveling	1-45
1.27-1	Survey Notes - Differential Leveling	1-46
1.27-2	Survey Notes - Differential Leveling	1-47
1.28-1	Profile and Cross Section Notes	1-51
1.28-2	Profile and Cross Section Notes	1-52
1.28-3	Profile and Cross Section Notes	1-53
1.28-4	Profile and Cross Section Notes	1-54
1.29-1	Profile Notes	1-56
1.29-2	Profile Notes	1-57
1.30	Sample Vertical Curve	1-60
1.31	Tabulation of Vertical Curve Data	1-61
1.32	Ties to Traverse Station	1-62
1.33	Deflection Angles	1-63
1.34-1	Notes Deflection Angle Traverse	1-65
1.34-2	Notes Deflection Angle Traverse	1-66
1.35	Circular Curves in Traverse Survey	1-67

1.36	Elements of Circular Curve	1-68
1.37	Layout of Circular Curve	1-70
1.38-1	Field Notes for Circular Curve	1-72
1.38-2	Field Notes for Circular Curve	1-73
1.39	Azimuths from North	1-74
1.40-1	Field Notes - Stadia Traverse Survey Horizontal Control	1-76
1.40-2	Field Notes - Stadia Traverse Survey Horizontal Control	1-77
1.41-1	Field Notes - Stadia Traverse Survey Horizontal and Vertical Control	1-80
1.41-2	Field Notes - Stadia Traverse Survey Horizontal and Vertical Control	1-81
1.42	Grid Survey Rectangular Field	1-82
1.43	Grid Survey - Irregular Field	1-84
1.44	Plus Stakes in Grid Survey	1-85
1.45-1	Field Notes for Grid Survey	1-89
1.45-2	Field Notes for Grid Survey	1-90
1.46-1	Traverse Notes	1-92
1.46-2	Traverse Notes	1-93
1.47	Location of Slope Stakes	1-96
1.47-1	Location of Slope Stakes	1-97
1.48-1	Field Notes - Slope Staking for Dam	1-98
1.48-2	Field Notes - Slope staking for Dam	1-99
1.48-3	Field Notes - Slope Staking for Dam	1-100
1.48-4	Field Notes - Slope Staking for Dam	1-101
1.49	Sample Plan of Storage Dam	1-105
1.50	Sample Plan of Gully Control Structure	1-106
1.51-1	Terrace Notes and Large Drainage Ditch	1-109
1.51-2	Terrace Notes and Large Drainage Ditch	1-110
1.52	Sample Plan Large Drainage Ditch	1-111
1.53-1	Field Notes Small Farm Drains	1-114
1.53-2	Field Notes Small Farm Drains	1-115
1.54	Procedure for Determining end areas by calculation	1-116
1.55	Example of Setting Alignment Stakes and Reference Points	1-117
1.56	Setting Grade Stakes for Structures	1-118
1.57	Batter Boards for Tile	1-119
1.58	Guide Meridian and Standard Parallels	1-121
1.59	Township and Range Lines	1-121
1.60	Numbering of Sections	1-122
1.61	Subdivision of Regular Section	1-122

PART 1

SURVEYING

1. GENERAL

Introduction

Surveying is the science of measuring and establishing lines, distances, angles and elevations on or near the earth's surface. Directions, positions, areas and volumes are thus determined from data of the survey. Also much of the information can be represented graphically by the construction of profiles, cross-sections, maps and diagrams. Each survey will present specific problems; however, if the principles are properly mastered, the skilled surveyor will have no difficulty in applying the proper method.

The surveyor must understand the limitations of the instruments he is using, the ever present possibility of errors affecting the process and mistakes due to carelessness. The precision and exactness necessary will change with the purpose of the survey; but whether the survey is rough or precise, sufficient checks must be applied both in field and in the preparation of plans so that unjustifiable errors and mistakes are eliminated from the final results.

It should be remembered that there can be no substitute for experience in surveying. Skill in surveying comes only with practice as in using a typewriter or driving an automobile. The beginner must continually review surveying procedures and conscientiously try to put them into practice, until the operations become very nearly automatic. Above all, he must not become discouraged by the initial mistakes. He must check and recheck his work until he is sure it is correct. It has been said, "A good engineer is one who assumes he is wrong, tries every way he can think of to prove he is wrong, and when he cannot thus prove he is wrong, cautiously concedes he may be right".

Purpose

The purpose of this part of the handbook, is to provide:

a. Detailed directions for the care and use of surveying instruments.

b. Step-by-step description of practical methods of surveying applicable to soil conservation activities.

c. Description of the methods used to gather basic information for the design of sound structures or for the movement of water at controlled velocities and the layout procedure for construction.

Scope

The earth has a curved surface. The geometric figure most nearly like its shape is a spheroid. Surveys that cover such a small portion of the earth's surface that its curvature can be neglected are called "plane surveys". Surveys which cover a large portion of the earth's surface must take into

1. GENERAL (CONT'D)

Scope (cont'd)

account the curvature of the surface and are called "geodetic surveys". In plane surveying we assume that the earth's surface is a plane. It therefore follows that a level line or a line within a level surface is considered mathmatically straight (not curved), that the plumb lines are parallel to each other at any point within the limits of the survey and the angles are considered as plane angles. The great majority of surveys are of this type.

The length of an arc eleven miles long lying on the earth's surface is only 0.05 ft. greater than the chord and the difference between the sum of the angles in a plane triangle and those of a spherical triangle is only one second for a triangle on the earth's surface covering an area of 75 square miles. From this it can be seen that the slope of the earth affects distance and angles only on surveys of large areas and great precision.

There are many kinds of surveys such as: land surveys, topographic surveys, engineering surveys for construction, route surveys, underground surveys, aerial surveys and hydrographic surveys. This part of the handbook will explain only basic principles of plane surveying for land surveys, topographic surveys, engineering surveys and route surveys as they apply to practices installed by the Soil Conservation Service.

Definition

In surveying, expressions are used that should be defined so that we have a common understanding of what is meant. Listed and defined below are some of the terms commonly used in plane surveying.

Level surface. This is a surface parallel with the spherical surface of the earth. The surface of a still lake is a good example.

Horizontal plane. This is a plane which is tangent to a level surface.

Horizontal line. Line which is tangent to a level surface.

Horizontal angle. The intersection of two lines in a horizontal plane form horizontal angles.

Vertical line. A line at right angles to a level surface. An example is the line established by the plumb bob.

Vertical plane. This is the plane of which a vertical line is a component.

Vertical angle. The angle formed by the intersection of two lines in a vertical plane. It is understood in surveying that one of these lines is horizontal and the vertical angle to a point is the angle in a vertical plane between the line to the point and the horizontal plane.

Horizontal distances are the distances measured along a level line.

1. GENERAL (CONT'D)

Definitions (cont'd)

Elevation of a point. This is the vertical distance of the point above (or below) some arbitrarily selected level surface. This surface is called a "datum" or datum "plane". Most elevations are referred to mean sea level datum, which is the average level of the ocean between low and high tide.

Difference in elevation. This is the vertical distance between two points. The procedure for determining this difference is called leveling.

2. SURVEYING EQUIPMENT

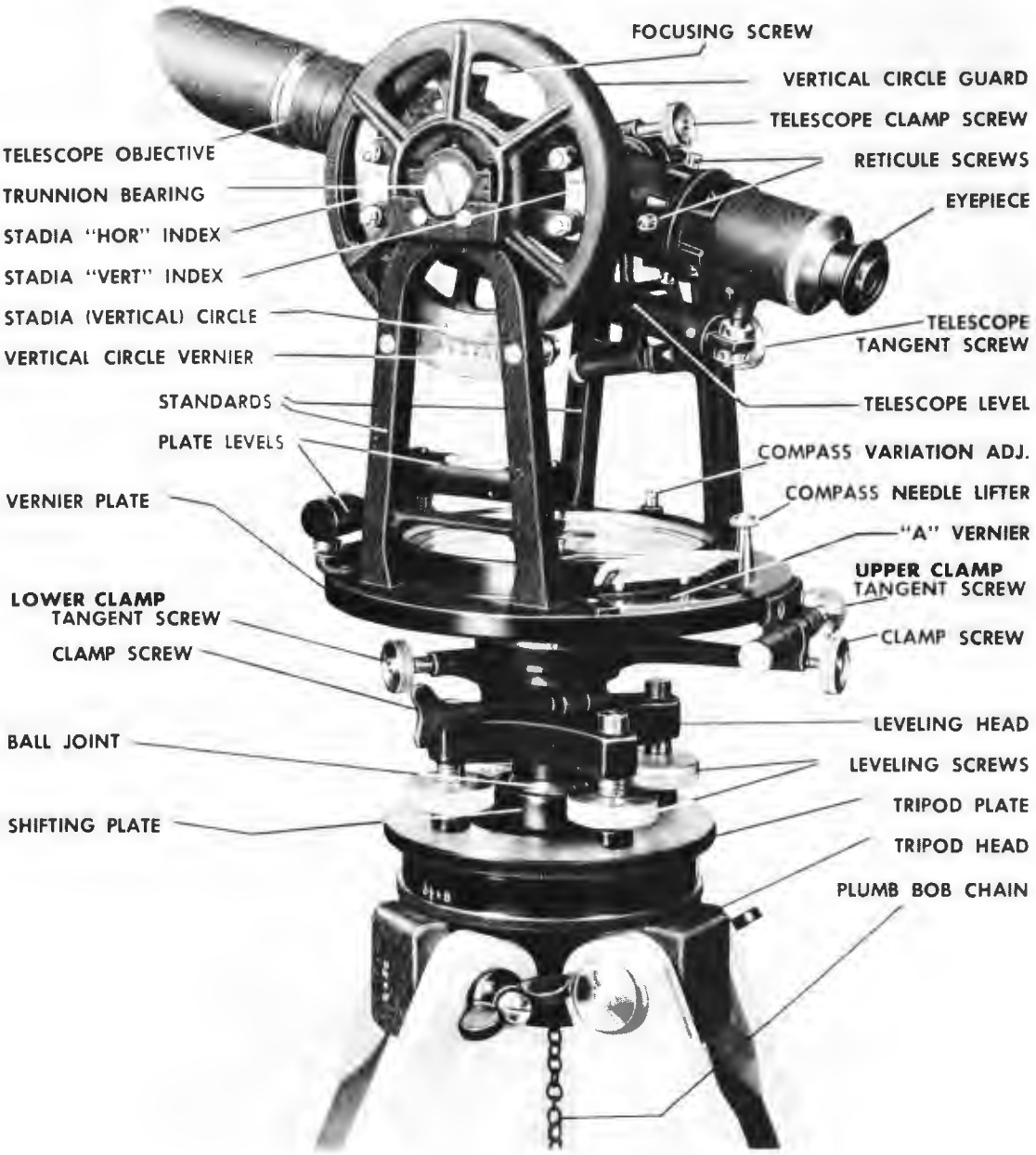
The main surveying instruments with accessories and uses are listed below:

Engineer's transit. This is a universal instrument, used primarily for measuring horizontal and vertical angles, prolonging or setting points in line, measuring approximate distances by the stadia principle and for leveling operations. It can also be used as a compass when equipped with a compass needle. Horizontal and vertical plates graduated in degrees and fractions are provided for measurement of angles. They are mounted at right angles to the horizontal and vertical axis. Spirit levels are provided for leveling the horizontal plates. A telescope, equipped with a spirit level, is mounted at right angles on horizontal axis supported by two uprights (standards) attached to the upper horizontal plate. In use the instrument is mounted on a tripod, and is equipped with a small chain and hook to which a plumb bob can be attached. This provides a means of centering the instrument over a point. The operator is called a transitman. See Figure 1.1.

Engineer's level. This is a telescope equipped with a sensitive spirit level. It is attached to a horizontal bar which is parallel to the telescope and has a vertical conical axis which rotates in a conical socket. Leveling screws are provided for leveling the instrument. In use it is mounted on a tripod and is employed for determining difference in elevation. The operator is called a levelman. See Figure 1.2.

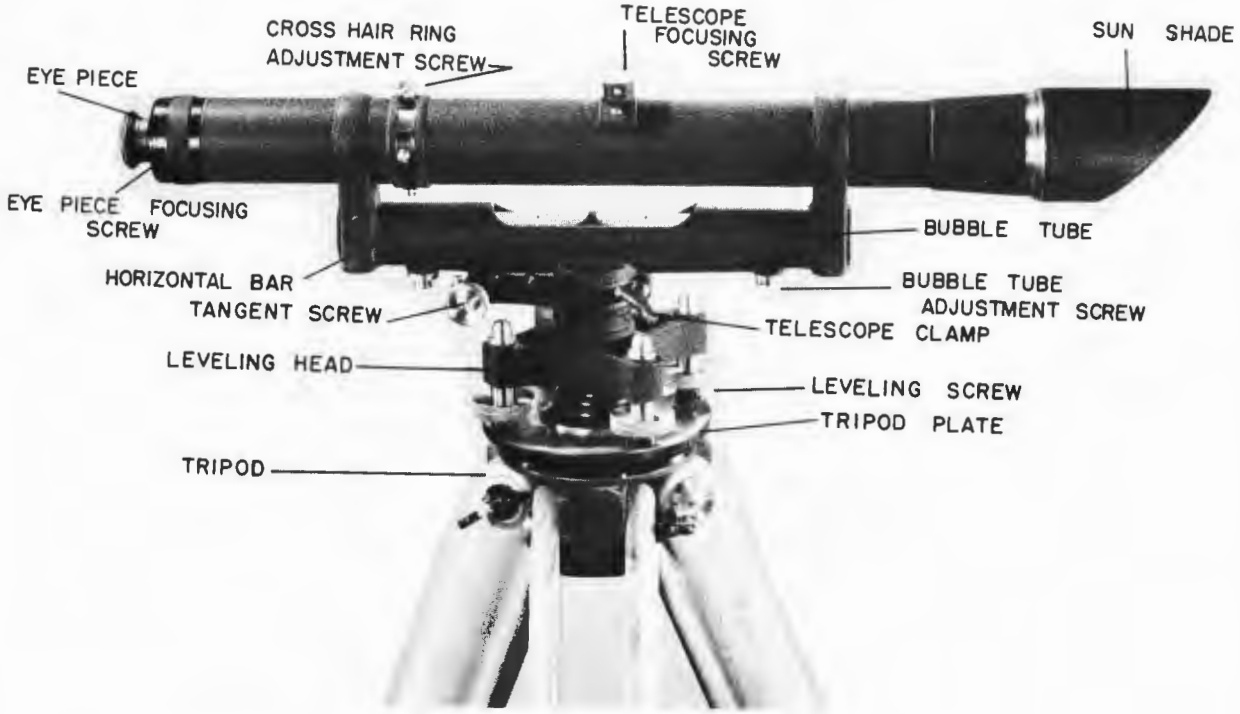
There are two types of levels; one called a "Dumpy level", the other a "Wye level". The essential difference between these two types is the manner in which the telescope is attached to the horizontal bar. On the "Dumpy level" the telescope is rigidly fixed to the crossbar and the instrument is so constructed that the optical axis of the telescope is perpendicular to the axis of the spindle. This results in an instrument that will hold its adjustment for a long time even with hard usage.

The "Wye level" has the telescope attached to the crossbar by means of two Y-shaped supports provided with clamps which fit over collars on the telescope. The supports are held in place by capstan nuts and can be adjusted to make the telescope parallel to the horizontal bar and at right angles to the spindle. This instrument will not stay in adjustment as well as the "Dumpy level" when subjected to hard use.



Courtesy: KEUFFEL & ESSER CO.

Engineers Transit
Figure 1.1



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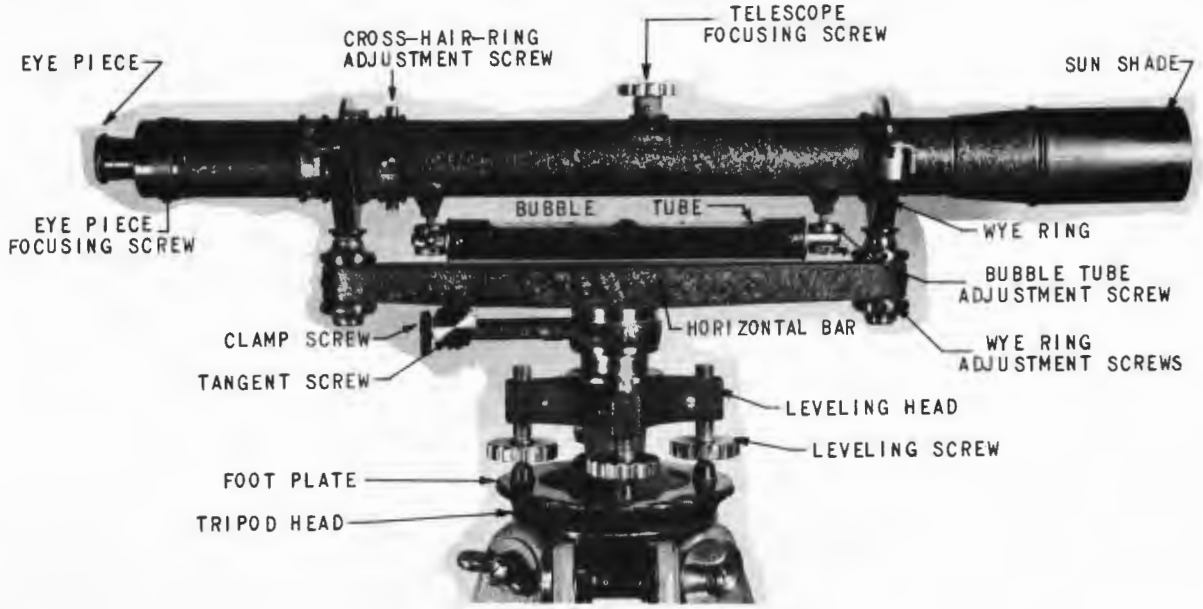
DUMPY LEVEL



WYE LEVEL

Figure 1.2

2. SURVEYING EQUIPMENT (CONT'D)

Range pole, Flag pole, or Flag. Either a steel or wood pole shod with a steel point, painted in alternating bands of red and white. It is used as a mark when making either angular or linear measurements. See Fig. 1.3.

Tapes or Chains. Various types of graduated flexible ribbons used for measuring distances. See Figure 1.4.

Chaining pins or Arrows. Steel pins about one foot long, used to temporarily mark the position of the ends of the tape when measuring distances. See Figure 1.5.

Level Rod. A wooden rod usually graduated in hundredths of feet. It is used in conjunction with the level for determining difference in elevation. It may be either a single piece or jointed. See Figure 1.6.

Stadia Rod. A graduated rod about 4 inches wide, 3/4 inch thick, and 12 feet long. Various graduating patterns are used, the object being to obtain a rod that can be easily read at distances of 1000 feet or more, See Figure 1.6.

Target. A sighting mark used in conjunction with level and stadia rods when it is difficult to read the rod directly. See Figure 1.6.

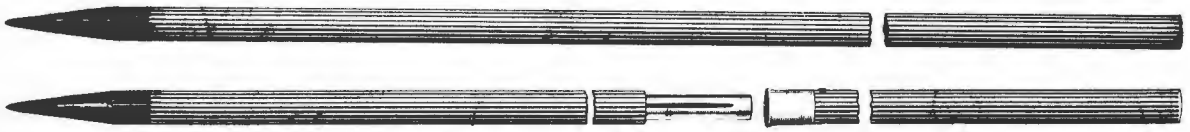
Plane Table and Alidade. A drawing board attached to a tripod in such a manner that it can be leveled, rotated and locked in the position selected. Drawing paper attached to the board allows plotting of the survey data in the field as the survey progresses.

There are two types of alidades: (1) the open sight and (2) the telescopic. The open sight alidade consists of a set of sights mounted on a ruler or straight edge in such a manner that the line of sight is parallel to the edges of the ruler.

The telescopic alidade consists of a telescope mounted on a horizontal axis which is supported by standards attached to the straight edge, either directly or by means of a post. The telescope is equipped with a vertical arc, either a striding or attached level bubble, and in addition many instruments are equipped with a Beaman stadia arc and a Vernier control bubble. See Figure 1.7.

The plane table and alidade are used most effectively for obtaining detail and topography. Mapping can be done rapidly and a more accurate representation of the terrain can be obtained since the operator can see the form of the ground that he is mapping.

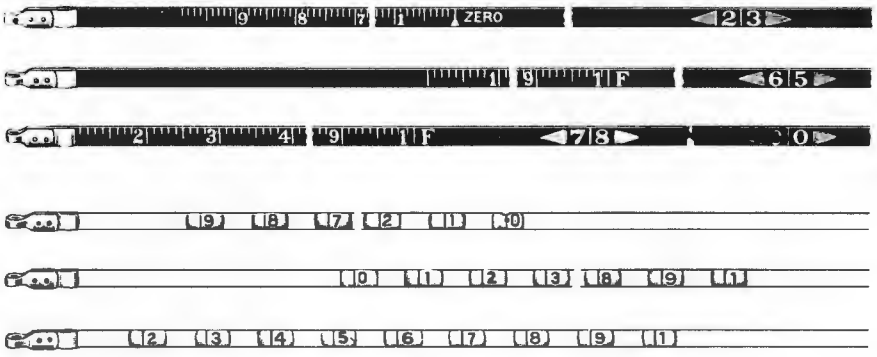
Hand level. An instrument used for approximate leveling. It is generally used for roughly determining the difference in elevation of points close to each other. It consists of a metal tube about 6 inches long on which a level bubble is mounted. When looking through tue tube the reflected image of the bubble and cross wire can be seen in the left-half side of the field of view, and the landscape in the other half. The level



Steel Range Poles

Wood Range Pole

RANGE POLES
Figure 1.3



Steel Band Tapes

Metallic Woven Tape

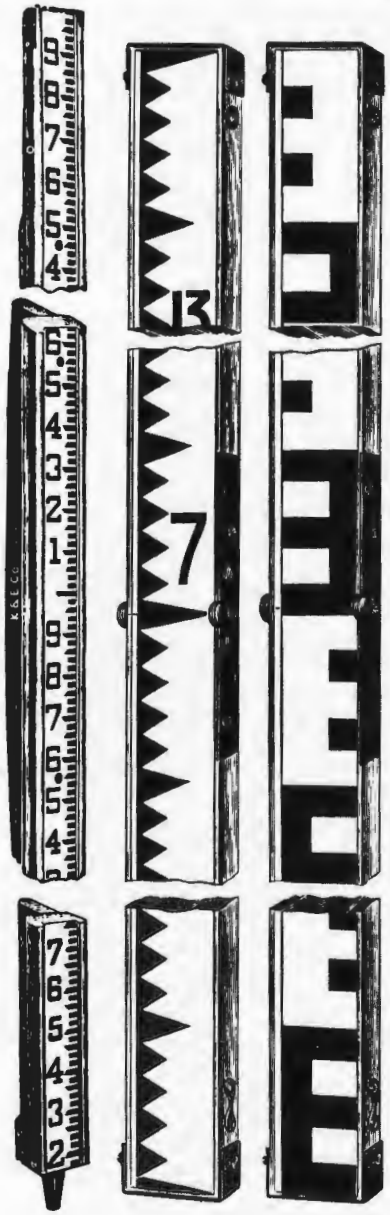
Courtesy: KEUFFEL & ESSER CO.

TAPES OR CHAINS
Figure 1.4

Chaining Pin or Arrow

Steel Carrying Ring for Arrows

Figure 1.5

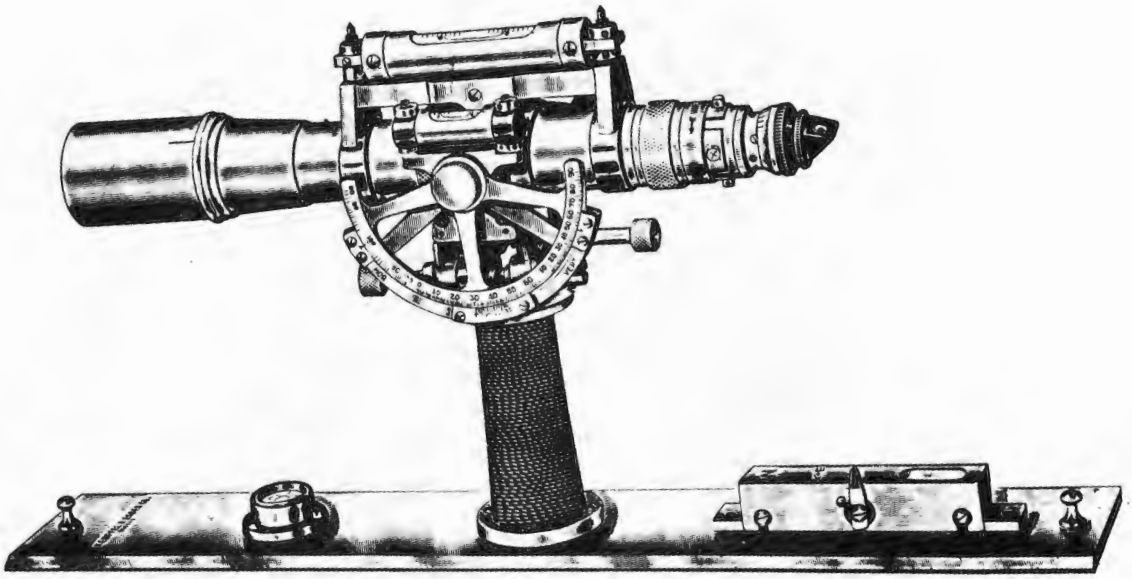


Stadia Rods

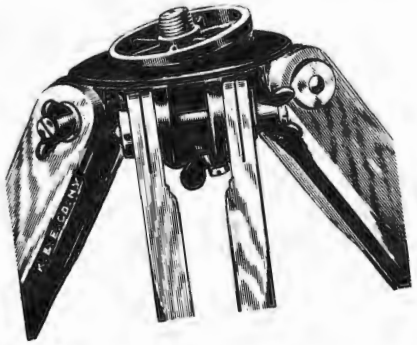
Leveling Rod with Target

Courtesy: KEUFFEL & ESSER CO.

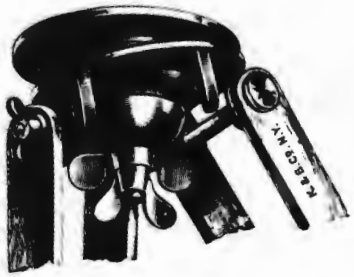
Figure 1.6



Geological Survey Alidade



Plane Table Tripod
with Extension Legs



Plane Table Tripod

Courtesy: KEUFFEL & ESSER CO.

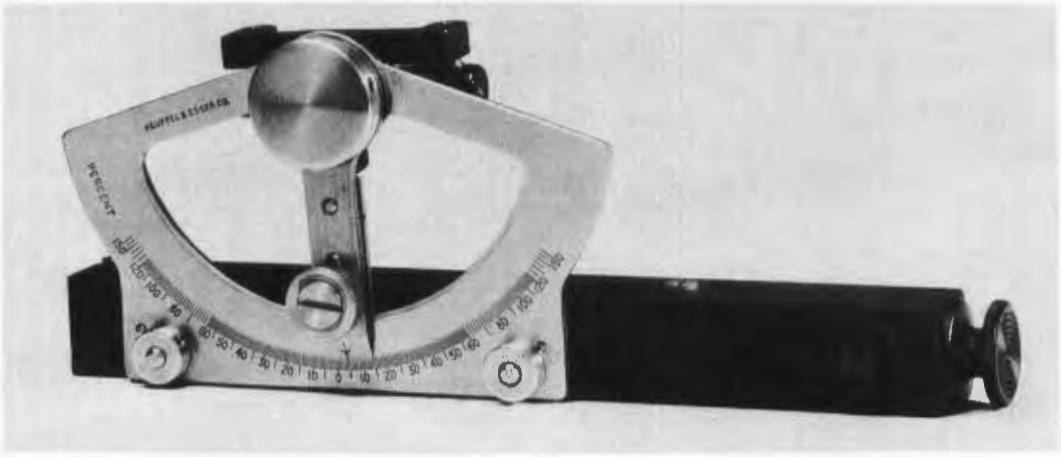
Figure 1.7

2. SURVEYING EQUIPMENT (CONT'D)

Hand Level (cont'd) is held by hand at the eye with the bubble vial up, and the farther end is tipped up or down until the cross wire bisects the bubble, the line of sight is then horizontal. See Figure 1.8.

Abney level or Clinometer. This instrument is similar to the hand level except that the bubble is attached to a vertical arc, thus vertical angles or percent of slope can be measured. See Figure 1.8.

ABNEY LEVEL



HAND LEVEL

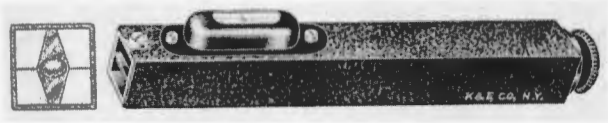


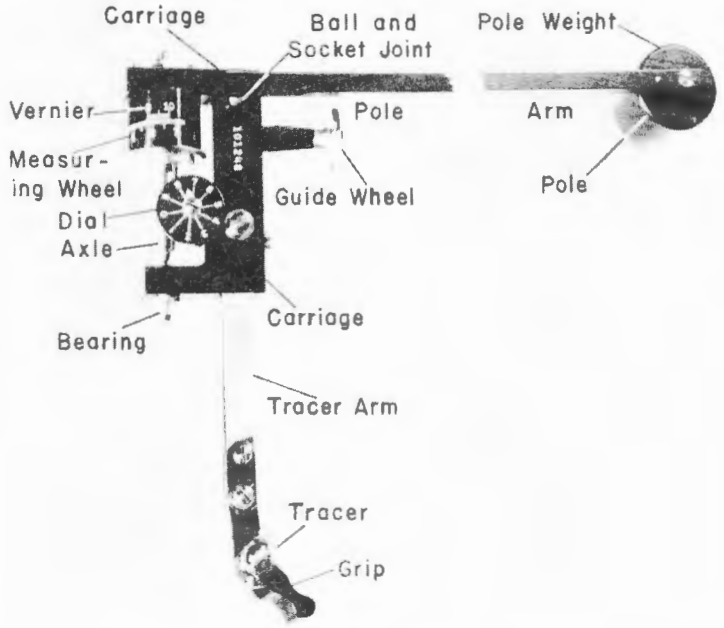
Figure 1.8

Courtesy: KEUFFEL & ESSER CO.

2. SURVEYING EQUIPMENT (CONT'D)

Planimeter. An office instrument used to measure the area of any plotted plane figure by passing a tracing point around the boundary line. See Figure 1.9.

PLANIMETER



Courtesy: KEUFFEL & ESSER CO. Figure 1.9

3. SURVEYING TERMS

In order to better understand the following portions of this part of the handbook, a few brief definitions of some of the more common surveying terms are pertinent.

Chaining. The act of measuring distances with a tape. The individuals making such measurements are called chainmen.

Flagman. The person who holds the flag or range pole on selected points as directed by the transitman.

Rodman. The person who holds the level rod and otherwise assists the levelman or topographer.

Back sight. (1) A rod reading taken, with the level, to a point the elevation of which is known. Also called + sight of B.S. (2) a transit sight or observation to a reference point on a line of known direction (generally to the rear).

3. SURVEYING TERMS (CONT'D)

Foresight. (1) A rod reading, taken with the level, to a point the elevation of which is to be determined. (2) A transit sight to a point along a line whose direction is to be determined (generally ahead).

Hub. Usually a heavy stake, with a tack in the top, which defines a point over which the transit is set.

Line. The course or route between points along which measurements of distance and angles are to be taken. Giving line means placing of a flag pole, pin or other object on line.

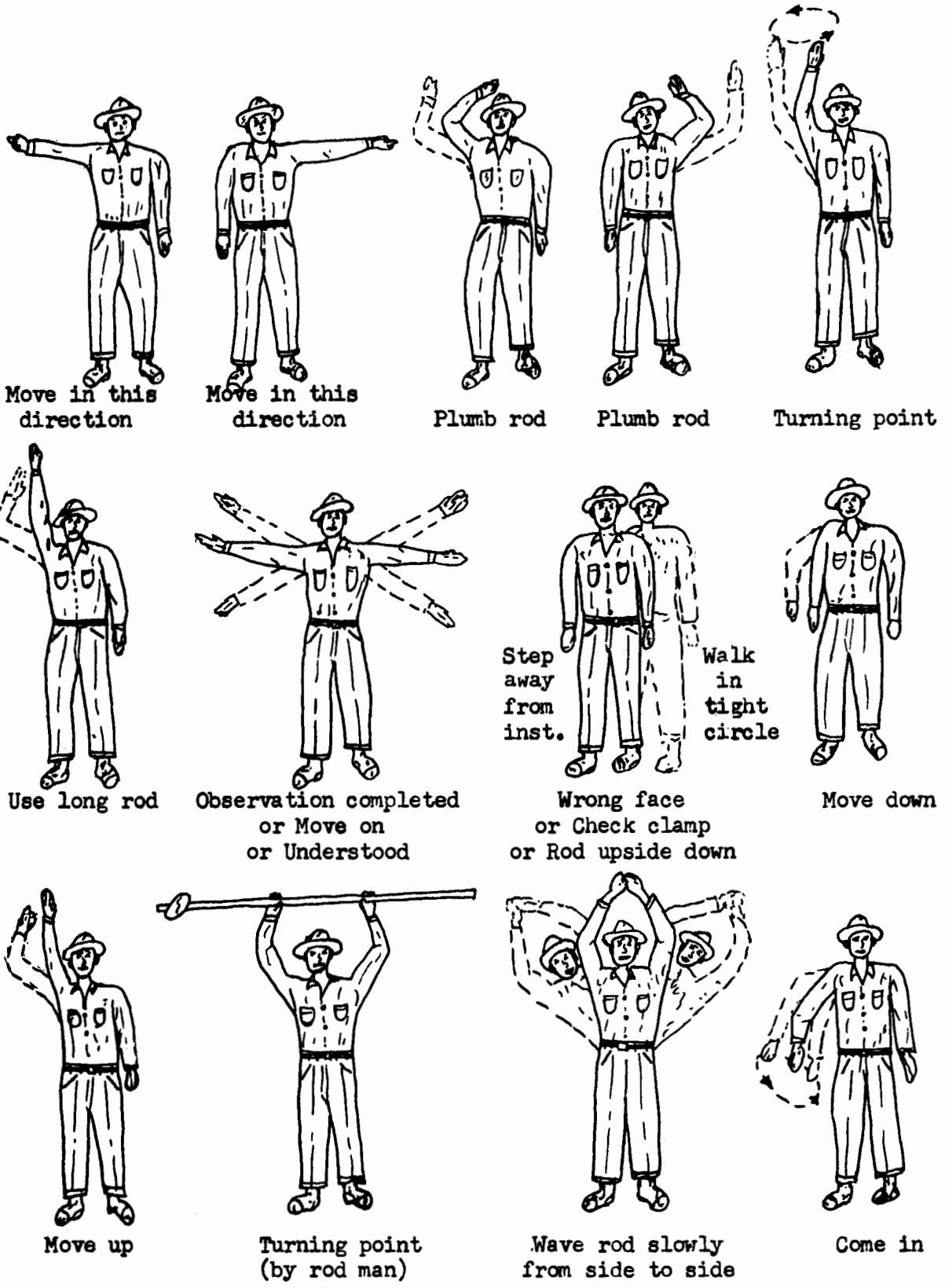
Turning Point. Generally a fixed point or object, temporary in character, on which the leveling rod is held first for a foresight, then for a backsight.

Bench Mark. A more or less permanent reference point or object, the elevation of which is known or established. It can also be used as a turning point.

4. HAND SIGNALS

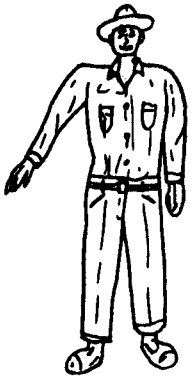
A good system of hand signals between different members of a surveying party makes a more efficient means of communication than is possible by word of mouth. Any code of signals mutually understood by the instrument man and the rodman is good if it works. The instrument man should be prompt in signalling the rodman when he is finished with the "shot" so that the rodman can move off promptly to the next point. It is also desirable to have a system of signalling numbers so that such information can be transmitted from rodman to instrument man or vice versa.

The code of signals illustrated in Figures 1.10 and 1.11, is suggested. This code may be enlarged upon or altered to suit the needs of the job. A definite code should, however, be determined and mutually understood in order to speed up the job.

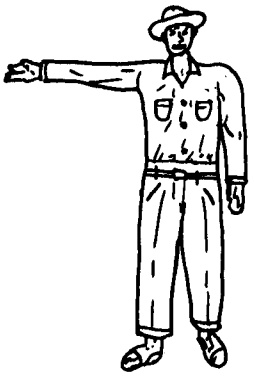


CODE OF HAND SIGNALS

Figure 1.10



"ONE"



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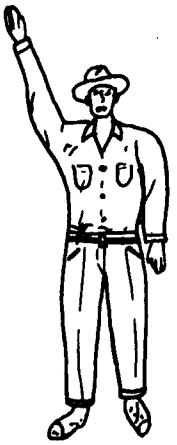
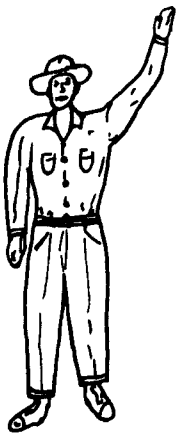
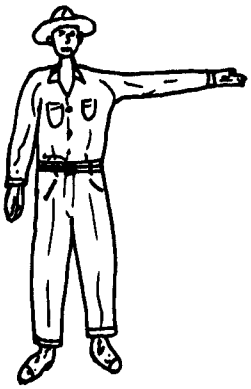


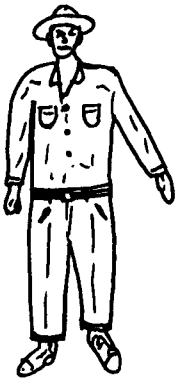
"THREE"



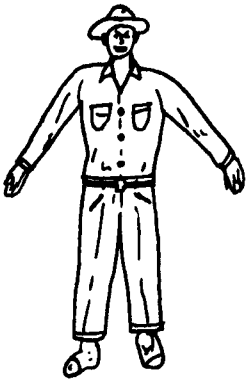
"FOUR"



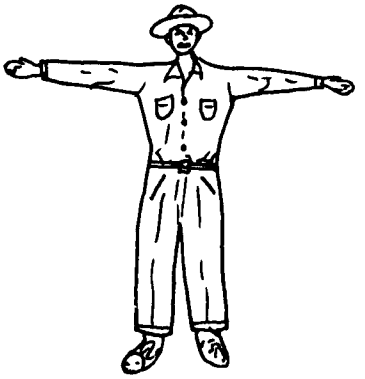
"FIVE"



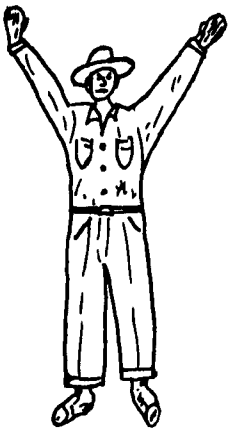
"SIX"



"SEVEN"



"EIGHT"



"NINE"

"ZERO"

"PLUS"

CODE OF HAND SIGNALS (NUMBERS)
Figure 1.11

5. MEASUREMENT OF HORIZONTAL DISTANCES

The procedure for measuring horizontal distances by pacing, chaining, and stadia are:

Pacing. Pacing may be used for approximate measurement when an error of two feet per hundred feet is permissible. Measurement by pacing consists of counting the number of steps between two points and multiplying the number by a predetermined "pace factor". Pace factors will usually vary between individuals. Each person having occasion to use this measurement method should determine his individual pace factor.

The pace factor for each individual is the average distance in feet per step. It can best be determined by pacing a measured distance (usually 500 feet) several times. It should be paced enough times so the number of paces for the distance does not vary over 2 or 3 paces. The "pace factor" then would be the distance in feet divided by the number of paces.

Some people prefer to use a stride in place of a pace. It consists of 2 paces, so the "stride factor" would be two times the "pace factor".

Measurement by pacing for preliminary profile work, and gridding for surface drainage surveys, is generally permissible.

Chaining. Chaining is the method of measuring horizontal distances with a steel tape. It is the most common method known and should be used for most measurements in order to get required accuracy.

Survey lines are measured or chained by stations. The distance between full stations is 100 feet. For this reason most steel tapes are 100 feet long. When a distance is referred to as so many stations, it means that number of 100-foot lengths. The fractional part of a distance between a full station is called a plus station. Fractions of a foot are indicated by decimals, either to the nearest 0.1 foot or 0.01 foot, depending upon the accuracy of measurement required. For example, a point on a line 309.2 feet beyond station 10+00 is indicated as station 13+09.2.

Stakes set along the line are marked with waterproof lumber crayon known as "keel". Markings are placed on the face of stakes so that as a person walks along the line in the direction of progressive stationing, the station markings are readily seen as each stake is approached.

Accurate chaining with a steel tape requires skill on the part of the chainmen in use of plumb bobs, chaining pins, range poles, hand levels and tension indicator apparatus. No attempt will be made to outline details for highly accurate chaining methods, since most chaining done for conservation jobs does not require the degree of precision required for city or lot surveys. In order to obtain sufficient accuracy in conservation work the following should be observed:

a. Keep tape on line being measured.
b. Keep uniform tension on tape for each measurement.
c. "Break" chain on slopes above 10%.
d. Accurately mark each station.
e. Keep accurate count of stations.

5. MEASUREMENT OF HORIZONTAL DISTANCES (CONT'D)

Chaining (cont'd)

The following procedure is generally used for chaining out a line within the accuracy limit. The line to be measured may be a meandering line along a drainage way or gully channel or it may be a straight line in a predetermined direction. In the former case the measurements are taken parallel, or nearly so, to the meandering line; but in the latter case a range pole is set ahead on the line as far as can be seen, or the direction is marked by a tree, fence post or other convenient point. This mark is used in sighting in a straight line from the point of beginning.

For purpose of this explanation it will be assumed a straight line is to be measured, and a stake has been set at the point of beginning marked 0+00. (See paragraph b, under Profiles and cross-sections for other methods of stationing the beginning station).

The head chainmen takes the zero end of the tape and advances in the general direction of the line to be measured. When he has gone the length of the tape the rear chainman will have observed that the 100-foot end is opposite the beginning point and he calls out "chain".

The rear chainman then sights in the head chainman on the line to be measured and holds the 100-foot mark of the tape exactly on the beginning stake. The head chainman pulls the tape straight and reasonably tight and sets a stake or pin exactly at the "zero" end of the tape.

The rear chainman calls out the number of his station (in this case 0+00) and the head chainman marks his stake 1+00 indicating one station has been measured.

Both chainmen then move forward along the line to be measured and the rear chainman again calls "chain" when the head chainman has gone forward 100 feet. The line is sighted in, stakes set and marked as before, each time the rear chainman calls off his station to the head chainman and the new station is given the next consecutive number and so marked.

When the head chainman reaches the end of the course he stops and the rear chainman comes forward to the last station set. The head chainman then holds the zero end of the tape at the end of the course and the rear chainman pulls the tape taut and observes the foot mark between the last station and the end of the line. If the tape is one on which the first foot is graduated in decimals the rear chainman holds the next larger foot mark on the last station and the head chainman reads the decimal of a foot. The distance in feet then between the last station and the end of the line would be one foot less than that indicated by the foot mark held by the rear chainman.

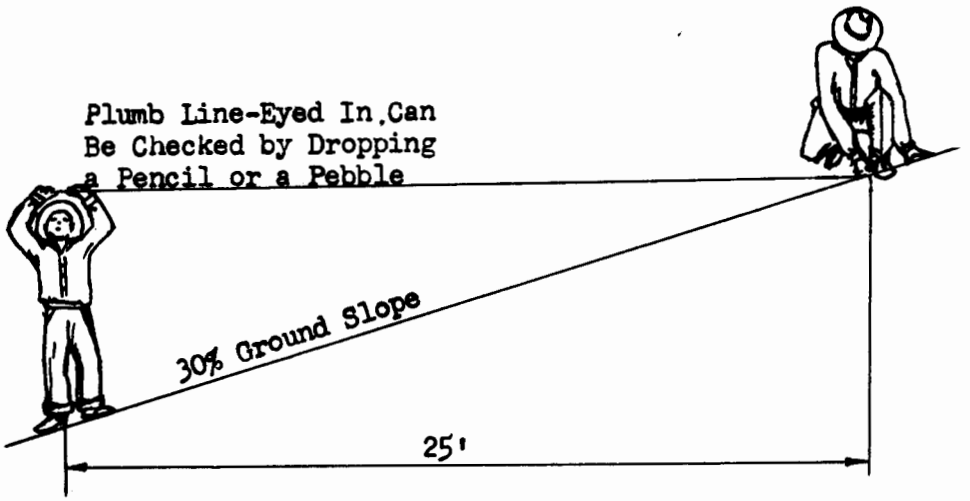
If the tape is one which has an extra foot graduated in decimals ahead of the zero mark, the rear chainman would hold the next smaller foot mark on the last station and the head chainman would read the decimal of a foot in this case the distance would be that indicated by the foot mark held by the rear chainman plus the decimal read by the head chainman.

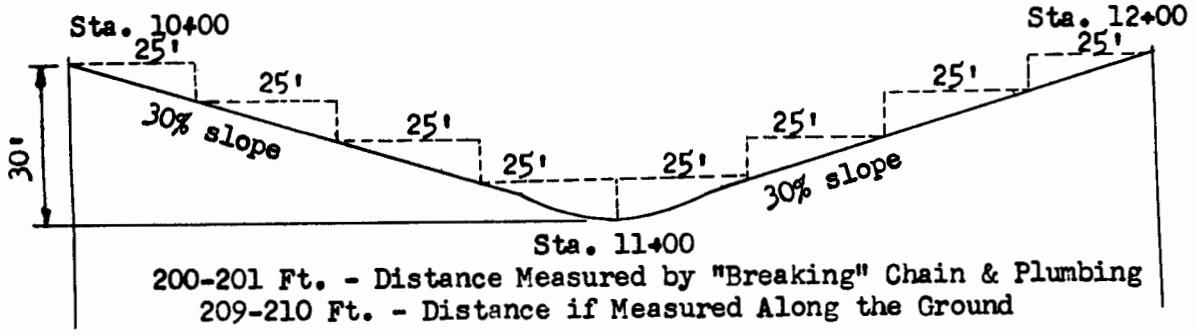
5. MEASUREMENT OF HORIZONTAL DISTANCES (CONT'D)

Chaining (cont'd)

If angles or other points not on full stations are to be established between the beginning and the end of the line they are set on plus stations. The next full station is then set and chaining continued by full stations as before. When curves are used at angle points the stationing follows along the curve. See Figure 1.34.

For chaining to the order of accuracy required in most soil conservation work it is not necessary to hold the tape level when measuring up or down slopes under about 3 percent. On grades steeper than 3 percent the uphill end of the tape should be held on the ground and the chainman at the other end should hold the end of the tape so that it is level and plumb down with a plumb bob or by sighting in. On grades over 10 percent such convenient lengths as can be held approximately level should be used and the down hill point plumbed down to the ground. This procedure is called breaking chain. Figure 1.12 below, illustrates the process and indicates the errors which can occur if this is not done on steep slopes.





200-201 Ft. - Distance Measured by "Breaking" Chain & Plumbing
209-210 Ft. - Distance if Measured Along the Ground

BREAKING CHAIN

Figure 1.12

5. MEASUREMENT OF HORIZONTAL DISTANCES (CONT'D)

Chaining (cont'd)

Where a line is to be measured on which no stakes are set the head chainman is responsible for keeping count of the number of stations. The procedure is the same as that described above except that most times chaining pins or arrows are used. Spikes (20d or larger) may be substituted for chaining pins. Many times the chaining pins are not provided, but the spikes are available. Regardless of the type of pin the procedure is the same and for purposes of explanation it will be assumed that spikes are used.

When chaining is begun the head chainman counts out 11 spikes, sticks one in the ground to mark the starting or zero point and puts 10 in a convenient pocket emptied of all other objects. When the first station is lined in and measurement completed the head chainman sticks a spike in the ground at that point and calls or signals to the rear chainman that measurement is completed. The rear chainman then pulls the spike at his location and puts it in one of his pockets that is free from all other objects, then moves forward to the next station at the same time the head chainman is moving forward in readiness for setting the next station. This process is continued until the head chainman uses his last spike. At this station 10 spikes have been used and 1000 feet has been measured. The head chainman calls "spike" to rear chainman, at which time the rear chainman moves up and delivers his collected 10 spikes to the head chainman. The head chainman then records 10+00 in his notebook. This process is continued until measurement of the line in question is completed. Suppose that measurement was completed when the head chainman had 4 spikes left and station 20+00 had been recorded in his notebook. This would mean that 10 minus 4 or six spikes had been used ahead of station 20+00 and the station at the end of the line would be 26+00.

Because of the wide variety in manner of marking tapes the surveyor should inspect the tape before it is used the first time to determine how it is marked.

Stadia. The stadia method for measuring horizontal distances require the use of a transit, level or alidade equipped with stadia hairs. There are three horizontal cross hairs and one vertical cross hair in this arrangement. The horizontal cross hairs are so spaced that any intercept between the top and bottom cross hairs when read on a level or stadia rod, if multiplied by 100 and the instrument constant is added, will give the distance between the instrument and the rod. It is most useful where a large amount of detailed topographic mapping is necessary and is further explained under this subject.

6. CARE OF EQUIPMENT

Transportation and Storage. Protection given to surveying equipment when stored or while being transported to and from the field will extend its useful life and contribute a great deal toward keeping the instrument in adjustment. Proper packing for shipment is also important.

6. CARE OF EQUIPMENT (CONT'D)

Transportation and Storage (cont'd)

Listed below are come precautions that should be observed:

a. Do not carry levels, transits, alidades, or other instruments in tool boxes or the body of pickups unless they are in their carrying cases and then only when the case is held securely in a special compartment properly padded to prevent jarring.

b. Carry engineering instrument, tripods, stadia rods, level rods, range poles, etc., in cars and trucks only when you have use for such equipment. Do not leave equipment in cars or trucks overnight.

c. All level and stadia rods should be protected by suitable carrying cases. Provide a place for tripods so they can be carried without coming into contact with other materials being transported. Protect such equipment from the weather and do not allow it to bounce around in cars or trucks with car chains, stakes, hatchets or other objects which may damage it.

d. Provide space in the office for storing the equipment in an orderly manner.

e. When shipping be sure all packing blocks fit tightly around the instrument, and that it is held securely in its case. Place the instrument case in a wooden box or corrugated carton with at least two inches of excelsior or equal type of packing. Tripods, rods and stadia boards should be placed in corrugated cartons provided with packing when being shipped. Suitable labels should be placed on the outside of packing boxes to assure careful handling.

Field Care.

a. The instrument should be handled carefully when removing it from its case.

b. It should be securely fastened to the tripod head.

c. Do not carry the instrument on the shoulder while passing through doorways or under low hanging branches.

d. Before climbing over a fence or similar obstacle the instrument should be placed on the other side with the tripod legs spread wide.

e. Never leave the instrument while it is set up, in fields where stock are grazing, on roads, or in areas of construction, or in any place where there is the slightest possibility of an accident.

f. Keep tripod legs well spread and see that they are firmly planted.

g. Tighten leveling screws only to a firm bearing; excessive tightening will injure the screws or warp the plate.

6. CARE OF EQUIPMENT (CONT'D)

Field care (cont'd)

h. Always use the sun shade. Attach or remove it by turning in a clockwise direction to avoid loosening the objective lens.

i. On transits see that the magnetic needle is raised off the pivot when not in use.

j. Dust caps should be replaced and instrument wiped clean before replacing it in the case.

k. Steel tapes are easily broken if not properly handled. Do not jerk the tape needlessly. Do not step on it or allow vehicles to run over it, and do not attempt to bend it around sharp corners. The most common cause of a broken tape is pulling or jerking on it when there is a loop or kink.

After each day's use, steel and metallic tapes should be wiped clean and dry with a clean cloth. Steel tapes should be given a light coat of machine oil by wiping with an oily cloth after cleaning. If rust spots are formed during a days use in wet weather, the tape may be cleaned with kitchen cleanser. Do not use a coarse abrasive such as sandpaper or emery cloth, as this will eradicate the markings.

Tapes using clamped or soldered sleeves for foot markings are commonly used without reels. Tapes without reels are done up in a figure-of-eight and then "thrown" into a circular shape. The method of "throwing" a tape does not lend itself well to a written description. This procedure should be learned from an experienced surveyor.

l. Rods should not be used as bars to loosen stones or stakes or as a hammer.

m. Hard knots in a plumb bob string indicate an inexperienced instrument man. Tie a sliding bow knot.

n. Never attempt to transport an instrument in a vehicle when it is mounted on the tripod.

7. SETTING UP INSTRUMENTS

Engineers Level. Before attempting to set up the level be sure that tripod wing nuts have been tightened until each leg when held horizontally will barely fall under its own weight. Then if a tripod leg is held in each hand the third leg is placed on the ground to act as a pivot, the two legs can be moved so as to make the foot plate nearly horizontal. Then without altering the horizontal position of the foot plate the two legs can be lowered to the ground. Pressure should then be applied to the legs to insure a firm and stable set-up. Be sure that the tripod legs are spread at such an angle that it is stable and that objects may be viewed through the telescope from a convenient posture.

7. SETTING UP INSTRUMENTS (CONT'D)

Engineers Level (cont'd)

The telescope should then be brought over one pair of leveling screws and the bubble approximately centered. The process should then be repeated with the telescope over the other pair. This procedure is repeated until the bubble remains centered or nearly so for any position of the telescope. Final centering of the bubble is usually easier if only one screw is turned rather than trying to adjust two opposite screws at the same time. The leveling screws should be tightened only enough to secure a firm bearing. Before attempting to take sights the cross hairs should be focused by means of the eyepiece. The telescope should be pointed at some light surface such as a white building or the sky and the eyepiece turned slowly in or out until the most distinct appearance of the cross hairs is obtained. It should then be pointed at, and focused (by means of the focusing screw) on a level rod, held by a rod man, on some point about one hundred feet from the instrument. The eye should then be moved slowly up and down to observe if the cross hair apparently moves over the face of the rod. If the cross hair does not appear to move it is properly focused. If movement is detected, further adjustment is necessary. Once the eyepiece has been adjusted no further adjustment is necessary so long as the same individual uses the instrument.

After focusing on the rod the bubble should be exactly centered in the level vial before the rod reading is taken. Be sure the rod is being held vertical or that the reading is taken with the rod in its most vertical position. Some surveyors ask the rodman to swing the rod back and forth over center on its base as a pivot, the minimum reading thus observed is the true vertical reading. Be sure not to lean on the instrument or step close to the tripod legs, since this will throw the instrument out of adjustment.

Engineers transit. Ordinarily the transit is set over some definite point, such as a tack in a hub. The plumb bob provides a means of centering the instrument over the point. The transit can be placed approximately over the point and the tripod legs adjusted until the tripod head is nearly level. The instrument can then be picked up bodily without disturbing the position of the legs and carefully set over the point; each leg should then be pressed firmly into the ground, at the same time adjusting it until the plumb bob falls within $\frac{1}{2}$ inch or less of the point and the foot plate nearly level. Two adjacent leveling screws can then be loosened and the transit head shifted until the plumb bob is over the point. Another method used by experienced surveyors is to grasp two legs of the tripod and place the third leg on the ground at such a point with respect to the hub that when the other two legs are allowed to touch the ground, the foot plate will be nearly level, the height of the telescope will be convenient and the plumb bob nearly over the tack in the hub. Obviously practice is required to perform this operation effectively. After the instrument is centered over the point, it is leveled. This is done by loosening the lower clamp screw and turning the instrument about its vertical axis until one of the plate level tubes is parallel to a line through a pair of opposite leveling screws. The second plate bubble will then be parallel to a line through the

7.SETTING UP INSTRUMENTS (CONT'D)

Engineers transit (cont'd)

other pair of leveling screws. Level the instrument by means of leveling screws and plate bubbles.

This is done by uniformly turning a pair of opposite leveling screws in such a manner as to move the thumbs either toward or away from each other. Thus one screw is tightened by the same amount that the other was loosened. This will tilt the leveling head and at the same time maintain definite support for it on both screws. The screws should rest firmly on the foot plate at all times but should not be allowed to bind. The other bubble is centered in a similar manner by the other pair of leveling screws. This process should be alternated until both bubbles are centered. The position of the plumb bob should now be observed. If it has moved off the point, it should be reset by shifting the head and releveling the instrument as previously described.

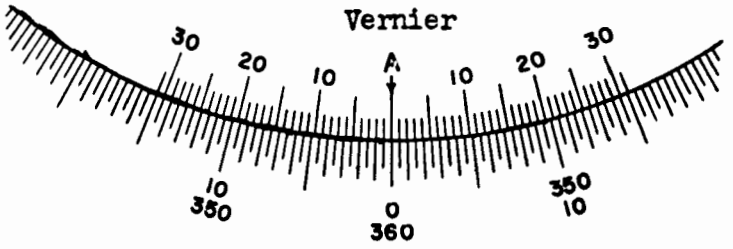
The instrument is now ready for the measurement of horizontal and vertical angles. Transits have two verniers for reading horizontal angles, the zeros being 180° apart. The horizontal circles of transits are graduated in various ways. They may be graduated to 30 minutes reading to one minute, graduated to 20 minutes reading to 30 seconds, graduated to 15 minutes reading to 20 seconds, or graduated to 20 minutes reading to 20 seconds. The graduations on the circle are usually numbered at intervals of 10° continuously from 0° to 360° in both directions from 0°. The inner row of numbers increases in a clockwise direction, while the outer row increases in a counterclockwise direction. The verniers are provided so that the angle can be read closer than the smallest circle division. In every case the graduations on the vernier depend upon the subdivision of the circle. For example, when the circle is graduated in half degree (30') spaces, the space between each line on the vernier will be 29/30 of the 30' arc space on the circle; thus an arc consisting of 29 divisions of 30' each (equivalent of 14°30' on the circle) is subdivided into 30 equal parts to obtain the space between the lines on the vernier. One division on the vernier then is 01' less in angular measurement than one division of the circle.

In Figure 1.13, a 01' vernier is shown with its zero opposite the zero (360) of the circle, ready to measure an angle. The vernier lines both sides of zero fail to match the lines on the circle by 01'; the next lines of the vernier fail to match the lines of the circle by 02'; and so on. Setting exactly at zero can best be accomplished by noting that the first vernier lines both sides of zero fail to match the circle divisions by the same amount.

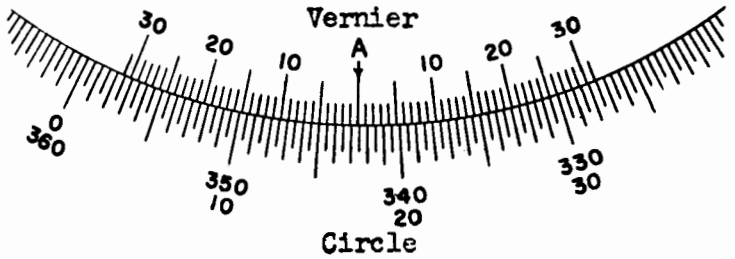
Figure 1.14 shows a one minute vernier reading 17°25' from left to right and 342°35' from right to left.

When horizontal angles are measured with the transit, the inner circle within the vernier moves with the telescope while the outer circle remains fixed. The zero of the vernier always points to the reading on the outer circle.

7. SETTING UP INSTRUMENT (CONT'D)



ONE MINUTE VERNIER SET AT 0°.
Figure 1.13



ONE MINUTE VERNIER
Reading 17° + 25' = 17° 25' from left to right
and 342° 30' + 05' = 342° 35' from right to left.
Figure 1.14

Measuring horizontal angles. When a horizontal angle is to be measured both the upper and lower clamps are loosened and the zero of the vernier is set close to 0 on the circle. The upper clamp is then tightened and by means of the upper slow motion screw, the index of the vernier is set exactly opposite 0 on the circle. The telescope is now directed at one of the objects to be sighted and when the object is in the field of view and near the vertical hair, the lower clamp is tightened. The vertical hair is set exactly on the object by means of the lower slow motion screw. The telescope should be focused carefully.

The upper clamp is now loosened and the telescope is sighted on the second object. The upper clamp is tightened, and the slow motion screw is used to bring the object on the vertical cross hair. The angle can now be read by adding to the circle reading the minutes read on the vernier. To

Courtesy: KEUFFEL & ESSER CO.

7. SETTING UP INSTRUMENT (CONT'D)

Measuring horizontal angles (cont'd)
eliminate instrument errors, the angle can be measured again with the telescope inverted and the mean of the measured angles taken. Another procedure is to measure the angle by repetition, once with the telescope direct and once reversed and the mean taken as the measurement of the angle.

Measuring vertical angles. The vertical angle is the angle in a vertical plane measured from the horizontal plane through the axis of the telescope to the point. When the point is above the horizontal plane, the angle is called a positive angle or angle of elevation; when the point is below the horizontal plane, the angle is called a negative angle or angle of depression. In the survey notes, they are designated by a + sign and a - sign respectively.

To measure a vertical angle, the instrument is carefully leveled and the telescope is directed to the object. When the object is observed in the telescope, the vertical motion is clamped and by means of the vertical motion tangent screw the middle horizontal cross hair is set exactly on the point. The reading on the vertical arc is the correct vertical angle, if the instrument is in adjustment and has been carefully leveled. The following conditions must exist: the line of sight and the axis of the telescope spirit level must be parallel; when the plate bubbles are centered, the plate must be horizontal; and the index of the vernier must be exactly opposite 0^{o} on the vertical arc, when the telescope bubble is in the center of the tube.

If the first requirement is not fulfilled, it is impossible to obatin a correct vertical angle with the vertical arc only. If the instrument has a full vertical circle, the error can be eliminated by reading the vertical angle first with the telescope direct and then reversed and taking the average of the two readings.

Plane Table and Telescopic Alidade. When setting up the plane table, be sure the tripod legs are spread well apart and firmly pressed into the ground. The table should be about waist high, so the operator can bend over it without resting against it. The board is leveled by placing the alidade near the center of the table top, loosening the tilting clamp, and tilting the board until the circular level bubble on the alidade is centered. The clamp is then tightened to hold it in this position. Care should be used to avoid having the alidade slide off the board when making this adjustment. Since few tables are sufficiently rigid to remain level as the alidade is shifted about, no special attempt is made to see that the board is perfectly level each time an observation is made.

In order to have the plotted angles theoretically correct, the plotted position of the station at which the plane table is set should be directly over the corresponding ground point. The degree of care to be used in bringing the plotted point over the ground point depends on the scale of the map.

For small scale map work the table is placed over the station without attempting to get the plotted point vertically over the ground point. On

Plane Table and Telescopic Alidade (cont'd) very large scale mapping the table is set over the point approximately oriented by sighting or magnetic needle, and then by plumbing the table is shifted bodily until the point on the paper is approximately over the station point.

The clamp which holds the table from rotating is now loosened and the table is oriented by rotating it on its vertical axis. Orientation may be done by various methods. For making rough small scale maps orientation by means of the magnetic compass is sufficiently exact. The table is rotated until the fixed bearing, usually magnetic north is observed, it is then clamped and all mapping at the station is carried on without disturbing the board. If the compass is mounted on the alidade, the straight edge is aligned with a meridian that was drawn at the first station occupied, and the table rotated until the needle points north. Orienting with the magnetic needle has an advantage over other methods in that an error in the plotted direction of one line will not introduce a systematic error in lines plotted from succeeding stations. The disadvantages are inability to determine the exact point on the graduated arc at which the needle comes to rest; magnetic variations due to local attractions or other causes; and sluggish needles, bent pivots or bent needles.

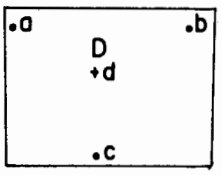
The table can also be oriented by back sighting along an established line which has been previously plotted. The advantage of this method lies in the increased precision obtained in orientation. A disadvantage is that the error in any previously plotted line is transferred to succeeding lines. This is the method generally used on intermediate and large scale mapping.

The table can also be located by the application of the principal of resection. This method is used in determining the position of any point on the map corresponding to the location of the point on the ground over which the plane table is set, providing three established points can be seen from the point in question and the positions of these three established points are already located on the map. The direction of the magnetic meridian should be established on the sheet prior to attempting the solution of the 3-point problem in order that the table can be oriented into the approximate correct position.

Assume the plane table is set up on an unknown point D, and points A, B, and C whose positions a,b, and c are plotted on the sheet and are visible from D. The problem is to find the location of d on the sheet corresponding to D on the ground. This location of d is found by trial. The plane table is oriented by estimations at point D. See Figure 1.15, below:

⊙A ⊙B

LOCATION OF A POINT ON PLANE TABLE



⊙C

Figure 1.15

Plane Table and Telescopic Alidade (cont'd)

If this estimated orientation is correct, resection lines from A, B, and C would intersect at point d. These resection lines are drawn with the edge of the alidade at a, a sight taken on A, and a line is drawn on the sheet. Similar lines are drawn with the edge of the alidade at b and c, sights being taken on B and C, and these lines drawn on the sheet. As the table, however, was oriented at D by estimation, these resection lines will not intersect at point d, but will form a triangle of error a',b',c'. See Figure 1.16. The size of this triangle will depend on the degree or error in orientation.

SOLUTION OF TRIANGLE OF ERROR (PLANE TABLE)

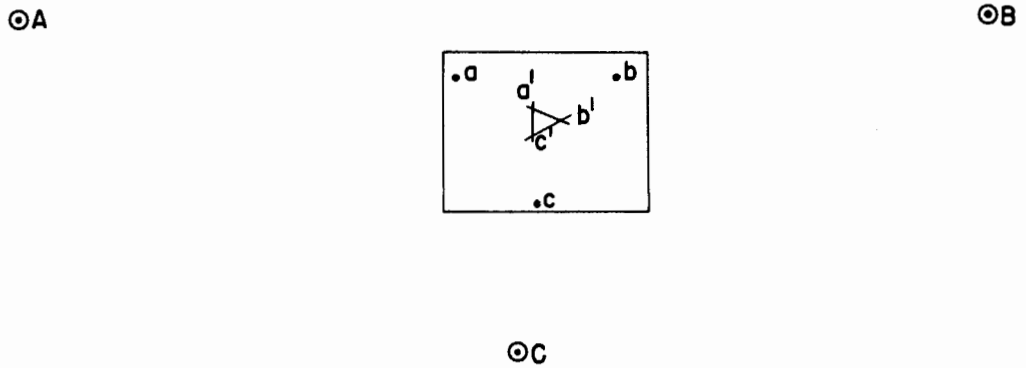


Figure 1.16

From the size and shape of the triangle, the correct position of (d) can be approximated closer. With the edge of the alidade on the line connecting this new point with a,b, or c, the board is reoriented by sighting on the corresponding point. Sights are taken on the other two points. These new lines will either intersect at a point which is the proper location for (d) or will form a much smaller triangle from which another approximation can be made. Usually, after some experience, two attempts are sufficient to properly orient the plane table and find the position of (d). In estimating the correct position of the point on the sheet from the triangle of error, the following geometric relations, illustrated in Fig. 1.17 should be borne in mind:

SOLUTION OF TRIANGLE OF ERROR (PLANE TABLE)

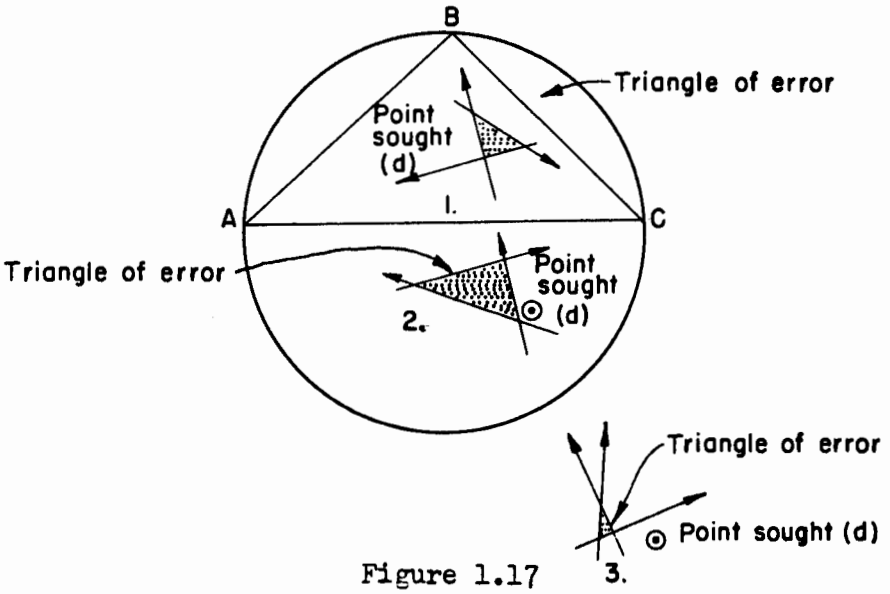


Figure 1.17

7. SETTING UP INSTRUMENT (CONT'D)

Plane Table and Telescopic Alidade (cont'd)

a. When D is within the triangle ABC, the point (d) will fall within the triangle of error, and will be farther from the line from the furthermost point than from either of the lines from the other two points.

b. When D is outside the triangle ABC but within the circle prescribed by the points of this triangle, (d) will fall outside the triangle of error, and is on the side of the line from the middle point opposite the intersections of the lines from the other two points.

c. When D is outside the circle prescribed by the points of the triangle ABC, it is outside the triangle of error and on the same side of the line from the most distant point as is the intersection of the lines from the other two points.

d. In every case, the distance of (d) from a resection line is proportional to the distance that D is from the point from which the resection line is drawn.

After orientation, the direction of lines are observed by rotating the alidade until the line of sight corresponds to the line to be observed. If stadia rods are used the distance can be read and plotted to the scale of the map. Elevations can also be determined and plotted. If the alidade is equipped with a Beaman arc, the computations for true horizontal distance and corrected elevations are simplified. The procedure is explained in detail under the subject, Topographic Mapping.

If object (building, trees, etc.) only are to be located, their position may be established by drawing rays from two previously plotted points. The intersection of the rays establishes the location of the objects.

8. CLEANING, INSPECTING AND LUBRICATING INSTRUMENTS

Cleaning, inspecting and lubricating instruments should be done by engineering personnel. Because of their training they are familiar with the various parts of the instrument and are not as apt to damage the instrument or throw it out of adjustment.

In setting up the instrument indoors for inspection or cleaning, be careful that the tripod does not spread, dropping the instrument on the floor. Complete spreading of the legs can be prevented by tying a stout cord around through the openings in the tripod legs. NEVER LEAVE AN INSTRUMENT STANDING IN A ROOM UNGUARDED.

Cleaning and lubricating is largely a matter of having the proper equipment and the will to use it. A small varnish brush should be used to dust off the exposed parts, do not use this brush on the lenses, as it becomes oily. A clean camels hair brush should be used to dust off the lenses. This brush should not be touched to the hands or face or otherwise geb oil on it. A piece of soft chamois or tissue paper and alcohol should be used to polish

8. CLEANING, INSPECTING AND LUBRICATING INSTRUMENTS (CONT'D)

the lenses. Several clean cloths which have been washed several times until free from lint, and a toothbrush should be used to clean screw threads. To remove gummed oil, wash parts in alcohol. Lubricants for surveying instruments should be carefully selected. Household, typewriter or other light machine oils are not satisfactory. The finest instrument or watch oil should be used. Oil should be applied sparingly.

Clamps that Bind. Clamps, arms and bearings are exposed to dust, and often oiled too freely. The oil collects and holds dust, then dries out leaving a gummy residue. This obstructs the free action of the clamp. If the dust is sharp, the clamp bearings may seize and bind. On a transit the upper motion clamp is the most likely to bind. Try this clamp by removing the tangent hanger screws, release the pressure of the clamp screw and slowly try to rotate the clamp arm, holding the telescope stationary. Do not force it to turn. Brush out the dust, then add instrument oil to the bearing. If there is no grit present the clamp can probably be turned gradually and may free itself. Should binding still occur, stop all turning and report the condition through proper channels to the area engineering specialist. He should then decide whether the instrument should be dismantled in the field or sent in for repair.

Clean and oil the tangent screw, spring barrel and slide frequently. Use a toothbrush and alcohol to clean the threads and a clean soft cloth for wiping other parts.

Seizure of Limb and Verniers. Examine the space between the limb and verniers with a pocket magnifier to see whether the parts have seized or some particles have become lodged between them. Often the seizure is ascribed to sticky spindles and socket. For that reason the advice can not be too often repeated, "Do not force any part to turn". Forcing will cause damage to the spindles and also the vernier graduations.

Spindles and Sockets. If the instrument does not spin freely on its vertical axis, the spindles and socket are perhaps sticky and dirty or the clamps are causing the binding. With the clamps loosened rotate the instrument. If it does not rotate freely the spindle and socket needs cleaning.

In an emergency these may be cleaned in the field by competent personnel who have had the proper training and experience and have the necessary facilities to do the job. Poor cleaning methods usually result in a defective spindle and socket; therefore, field men are strongly urged not to take the spindle and socket apart for cleaning.

When oiling the instruments use only a drop of oil at a time. Apply it to clean surfaces only. Wipe off excess oil so it will not collect dust. Dust thus collected makes an excellent grinding compound. If not cleaned regularly the parts will wear rapidly and the metallic dust in the grease and grit may ultimately cause the parts to bind and cause permanent damage.

A regular system of inspection, cleaning and adjustment of all instruments by the engineering specialist will do much to prolong the life and keep instru-

8. CLEANING, INSPECTING AND LUBRICATING INSTRUMENTS (CONT'D)

ments in good working order and adjustment. A record card showing date, work done, and by whom should be kept in the instrument box.

Lenses. Frequently inspect the objective lens to see that it has not become loose in its setting and that the setting is tightly screwed into the objective slide. Do not take the objective lens apart. When carrying the instrument in the rain, cover the objective lens with its cap. Fogging of lenses is caused by the presence of moisture on one or more of the lens surfaces. When working in rainy or foggy weather, moisture will sometimes penetrate to the interior. Fogging is generally caused by condensation of moisture from the air. The quickest way to get rid of foggy lenses is to take the instrument into a warm dry room.

Dust should be brushed from both the objective and eyepiece lenses. A clean camels hair brush should be used. Clean with soft chamois or tissue paper after first breathing on the lens. If very dirty, use a little alcohol.

Axle Bearings. If the telescope revolves too freely about its axis, it is probably due to loose axis bearings, cap screws or worn bearing. To adjust to proper tension, tighten each side gradually with a screw driver or adjusting pin. Some models have a laminated shim inserted under the bearing caps. When the bearings are worn, a lamination may be removed from the shims and the cap screws set up tightly again. Constant use of the telescope in its normal position will cause the axle bearings to wear out of round. To prevent this, use the telescope frequently in the reversed position or spin it a few times each day that the transit is used.

Some bearings are provided with clearance space into which dirt can work and free itself. The telescope and axle should be removed occasionally from the standards and thoroughly cleaned. Remove the vertical circle guard. Loosen the cap screws and lift off the cap and screws together being careful not to lose the shims if there are any. Clean with a toothbrush using clean oil. Wipe off free oil and replace.

Binding or Freezing. Binding or freezing of the bottom plate to the tripod head, the tangent screws or the leveling screws is often due to dust particles lodging in the threads. Leveling screws may also bind or freeze when one screw is turned mor or less than the opposite one during the leveling process.

Graduations. Dust should be removed with a soft, clean rag or brush. Do not clean in the direction of the graduations - move across them.

Leveling Screws. Clean and oil frequently in the same manner as used for tangent screws.

Tripods, rods and tapes used in rain, mud or snow should be carefully cleaned and dried after use.

Repair. Whenever major cleaning or repair jobs are necessary, arrangements should be made with the administrative officer to have the instrument sent to the manufacturer or other reputable instrument repair company.

9. ADJUSTMENT OF INSTRUMENTS *

By "adjustment" of a surveying instrument it is meant bringing of the various fixed parts into proper relation with one another, as distinguished from the ordinary operations of leveling the instrument, aligning the telescope, etc.

The frequency with which adjustments are required depends upon the instrument, its care, and the precision with which measurements are to be taken. On ordinary surveys, it is a good practice to test the critical adjustments frequently, especially on long surveys where occasional checks on the accuracy of the field data are impossible.

Before adjusting the instrument, see that no parts (including the objective lens) are loose.

Another factor to bear in mind before making adjustments is to properly focus the eyepiece and cross hairs. That is, the cross hairs must be in the focal plane of the eyepiece. To determine if the cross hairs are in the focal plane of the eyepiece, sight the vertical cross hair on a point. Move your head slightly and slowly sideways and observe if the vertical hair moves off the point. If it does, a condition known as parallax exists. This indicates imperfect focusing. To focus the eyepiece, point the telescope at the sky or at some white surface and turn the eyepiece until the cross hairs appear as dark and distinct as possible. Test for parallax- - after a few trials a position is found where there is no parallax. This position of the eyepiece will not need to be changed for that observer. Each observer, however, will have to focus the eyepiece for his personal eye condition.

Adjustment of the transit. A transit is in adjustment when:

a. The axis of the plate bubbles are perpendicular to the vertical axis.
b. The vertical hair is perpendicular to the horizontal axis.
c. The line of sight is perpendicular to the horizontal axis.
d. Standards are exactly at the same height.
e. The line of sight and the axis of the telescope level are parallel.
f. When the telescope is leveled by the telescope level, the zeros of the vertical arc and vernier should coincide.

Figure 1.1 shows the most important parts of a transit and will be referred to in discussing the various adjustments. In order that the effect of one adjustment may be reflected in the others to a minimum degree, they must be made in the following order: (1) plate bubbles, (2) vertical cross hair (3) line of sight, (4) standards (5) telescope bubble.

* Reprinted by permission from "Elementary Surveying", Volume I, by Charles B. Breed and George L. Hosmer, 1925 Edition, and "Surveying" by Charles B. Breed, 1942 Edition, published by John Wiley & Sons, Inc. (See Region 5 Engineering Handbook)

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Plate Bubbles. To adjust the plate levels so that each lies in a plane perpendicular to the vertical axis of the instrument, set up the transit and bring the bubbles to the center of their respective tubes by means of the leveling screws. Loosen the clamp and turn the plate 180° about its vertical axis and see if the bubbles remain in the center. If they move from the center, half this distance is the error in the adjustment of the tube. See Figure 1.18 below. The adjustment is made by turning the capstan-headed screws on the bubble tube until the bubble moves half way back to the center as nearly as this can be estimated. Each bubble must be adjusted independently. The adjustment should be tested again by releveling and reversing as before, and the process continued until the bubbles remain in the center when reversed. When both levels are adjusted, the bubbles should remain in the centers during an entire revolution about the vertical axis.

ADJUSTMENT OF THE PLATE BUBBLES

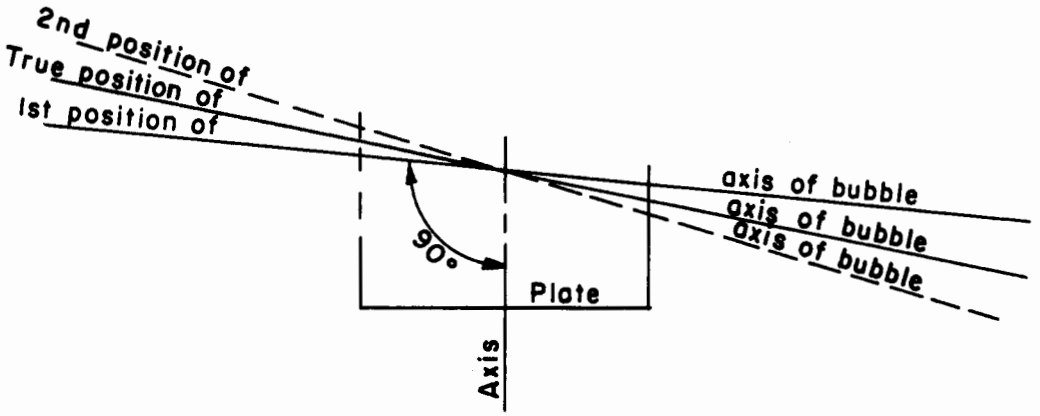


Figure 1.18

Vertical Cross Hair. To put the vertical cross hair in a plane perpendicular to the horizontal axis - sight the vertical hair on some well defined point, and leaving both plates clamped, elevate or depress the telescope. (See Figure 1.19)

ADJUSTMENT OF THE CROSS-HAIRS
(First Part)

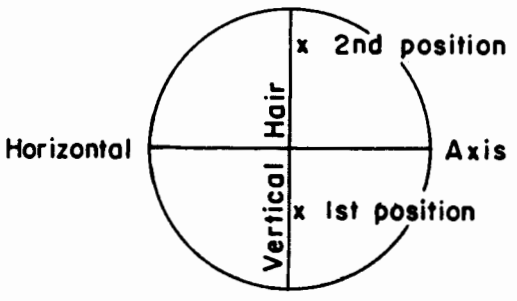


Figure 1.19

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Vertical Cross Hair (cont'd)

The point should appear to travel on the vertical cross hair throughout its entire length. If it does not, loosen the screws holding the cross hair ring, and by tapping lightly on one of the screws, rotate the ring until the above condition is satisfied. Tighten the screws and proceed with the next adjustment.

Horizontal Cross Hair. To make the line of sight perpendicular to the horizontal axis * (See Figure 1.20) set the transit at some point **A**. Level up, clamp both plates, and sight accurately on some point at B which is approximately at the same level as **A**. Reverse the telescope and set C in line with the vertical cross hair. B, **A** and C should be in a straight line. To test this, turn the instrument about the vertical axis until B is again sighted. Clamp the plate, reverse the telescope, and observe if point C is in line. If not, set point D in line just to one side of point C and then the cross hair ring must be moved until the vertical hair appears to have moved to point E, which is set at one-fourth the distance from D toward C, since in this case a double reversal has been made.

ADJUSTMENT OF THE CROSS HAIRS
(Second Part)

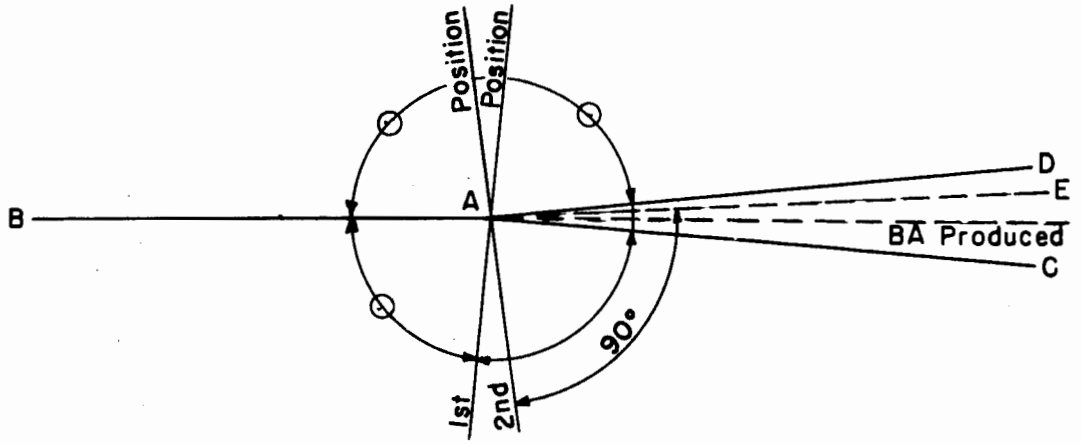


Figure 1.20

* In making the adjustment in the shop with collimators, instrument makers seldom level the transit carefully. In field adjustments it is desirable, although not necessary, to level the instrument. The essential condition is that the vertical axis shall not alter its position.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Horizontal Cross Hair (cont'd)

The cross hair ring is moved by loosening the screw on one side of the telescope tube and tightening the opposite screw. If D falls to the left of C, then the cross hair ring should be moved to the left; but if the transit has an erecting eyepiece, the cross hair will appear to move to the right when viewed through the telescope. If the transit has an inverting eyepiece, the cross hair appears to move in the same direction in which the cross hair is actually moved.

The process of reversal should be repeated until no further adjustment is required. When finally adjusted, the screws should hold the ring firmly but without straining it.

Standards. To make the horizontal axis of the telescope perpendicular to the vertical axis of the instrument (See Figure 1.21) set up the transit and sight the vertical cross hair on a high point A, such as the top of a church steeple. Lower the telescope and set a point B in line, on the same level as the telescope. Reverse the telescope, turn the instrument about its vertical axis, and sight on B. Raise the telescope until the point A is visible and see if the cross hairs come on A. If not, note point C in line and at same height as A. Then half the distance from C to A is the error of adjustment.

ADJUSTMENT OF THE STANDARDS

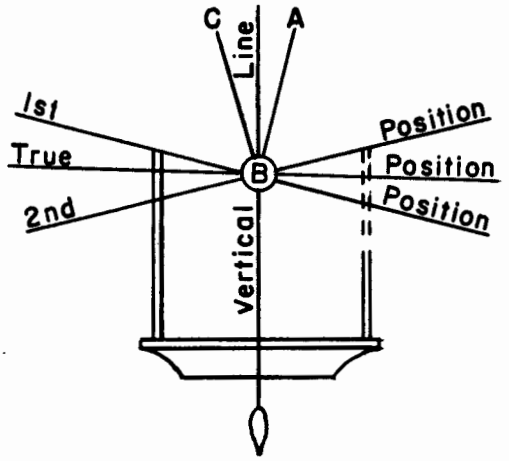


Figure 1.21

Loosen the screws in the pivot cap and raise or lower the adjustable end of the horizontal axis by means of the capstan-headed screw under the end of the axis. Repeat the test until the high and the low points are both on the cross hair in either the direct or the reversed positions of the transit. The adjusting screw should be brought into position by a right-hand turn, otherwise the block on which the horizontal axis rests may stick and not follow the screw. The cap screws should then be tightened just enough to avoid looseness of the bearing.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Telescope Bubble. To make the line of sight parallel to the axis of the bubble, perform the two peg test. Set two pegs of stakes 200 or 300 feet apart. Set the instrument midway between them. Take a rod reading on each peg with the telescope bubble centered at each reading. See Figure 1.22. The difference in the two rod readings (4.19') gives the true difference in elevation between the pegs, regardless of whether the instrument is in adjustment or not.

Now set the instrument at A, preferably the high peg, and read the rod (which is held against or within a half-inch of the eyepiece). Note where the center of the eyepiece hole touches the rod. You may prefer to take this reading backward through the telescope. This reading, plus or minus the true difference in elevation between the pegs as previously determined, gives the true reading on B, in this figure, (9.29 feet) which makes the line of sight horizontal. With the horizontal cross hair on this true reading on the rod at B, the line of sight is parallel to the axis of the bubble if the bubble is in the center of the tube.

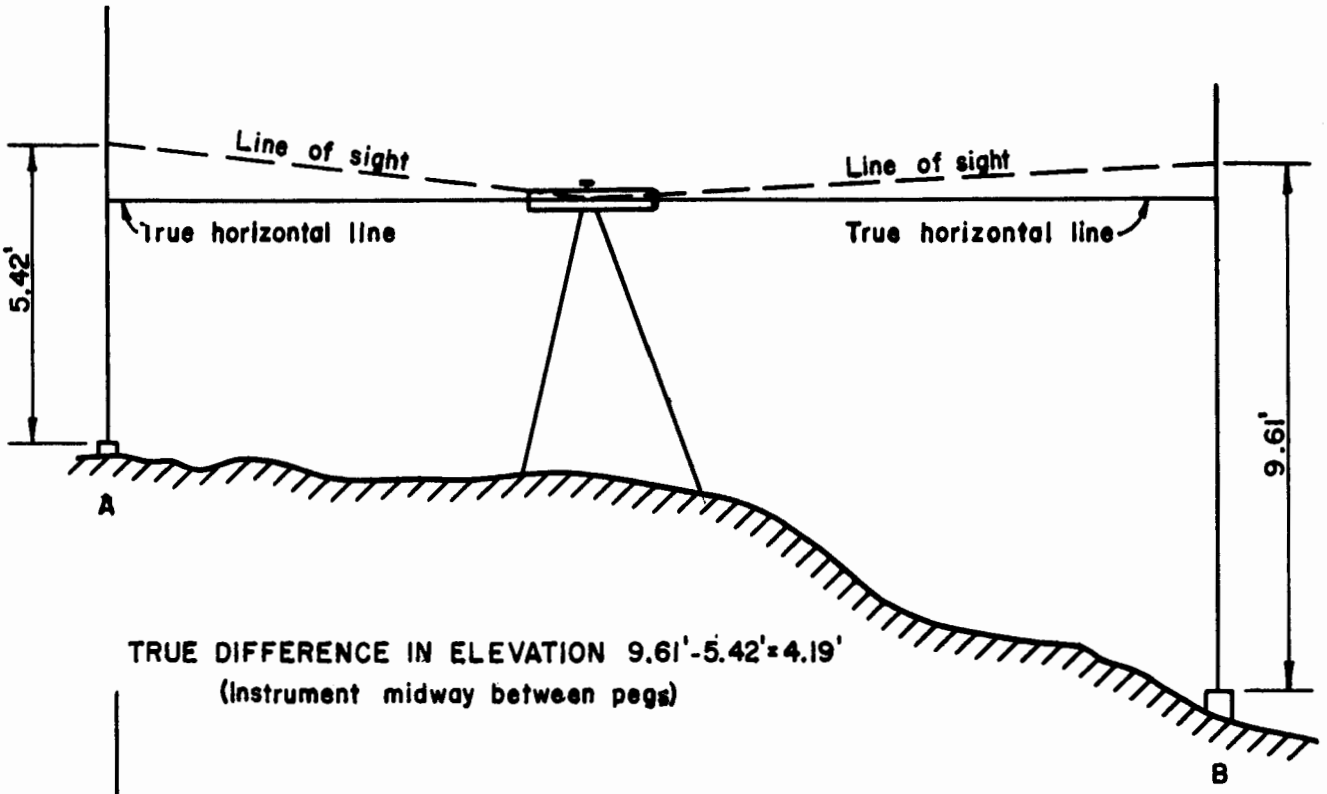
If it is out of adjustment, raise or lower one end of the telescope bubble tube by turning the capstan nut until the telescope bubble is centered; and finally again noting the true reading at B. After this adjustment has been made, the vertical arc and the vernier zero-line should be examined to see whether they coincide when the telescope bubble is in the center of the tube. If not, the vernier may be moved by loosening the capstan-headed screws which hold the vernier to the standard. The zero lines are brought together and the screws tightened.

Adjustment of the Level. There are two types of engineer's levels; one is known as the Wye level and the other as the Dumpy level (Figure 1.2), the former so named because the telescope is held in Y-shaped supports.

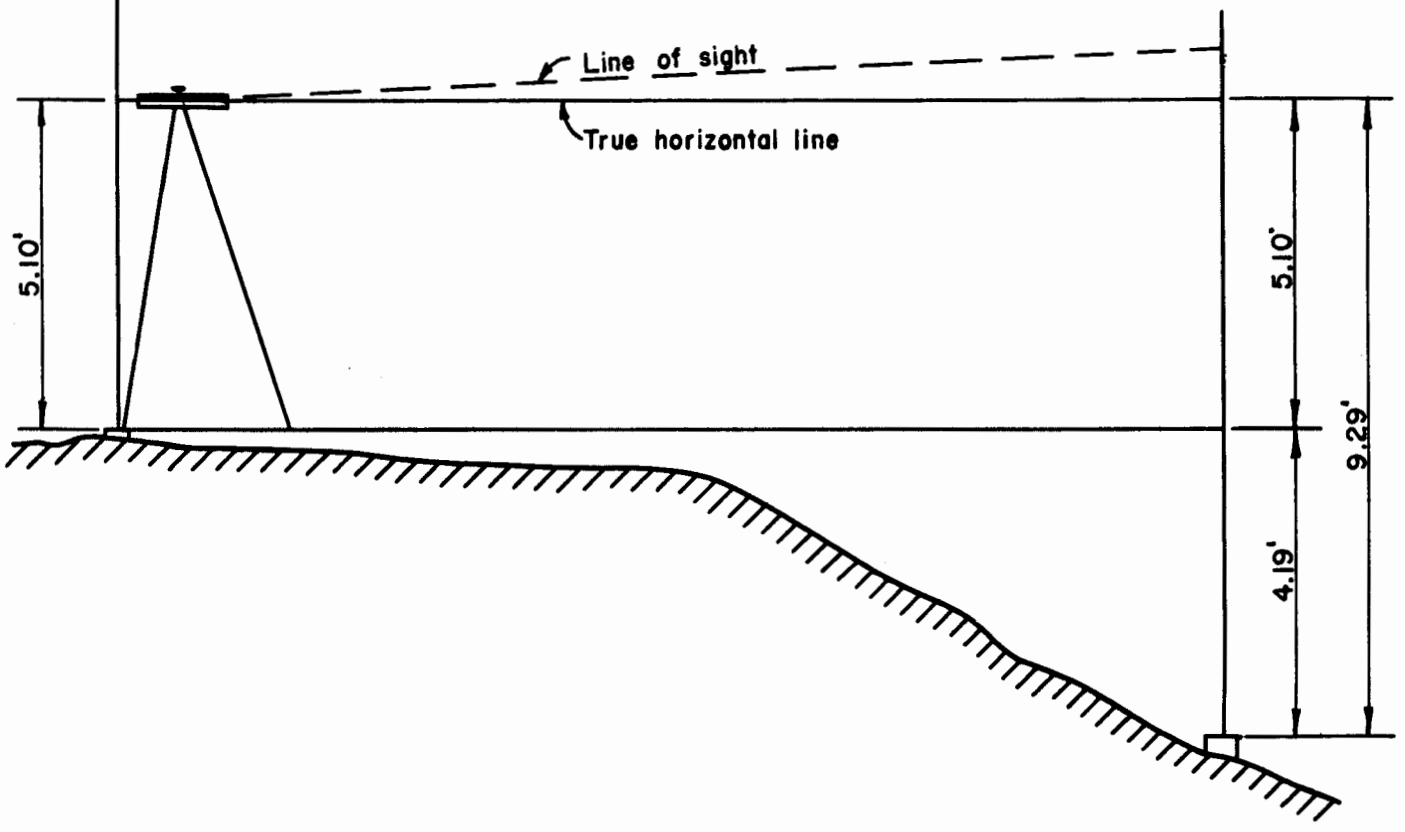
The two major adjustments of the level are:

(1) the adjustment to make the line of sight parallel to the axis of the bubble tube.
(2) the adjustment to make the bubble tube axis perpendicular to the vertical axis.

If the first one is made, error due to the second will always be eliminated if the rod readings are taken only at the insant when the bubble is in the center of the tube; but centering the bubble will not eliminate the error due to the line of sight not being parallel to the bubble tube axis. In this case the line of sight will fall below the true horizontal and thus give a rod reading which is too small, or it will be above the true horizontal and give a rod reading which is too large. In either case, the amount of error in the rod reading will be exactly proportional to the distance from the instrument to the rod. Consequently, such an error will be eliminated from the results if the sum of the distances to the backsights and the sum of the distances to the foresights are equal; these distances may be obtained satisfactorily by pacing. This is one of the most important principles to be observed in leveling work.



TRUE DIFFERENCE IN ELEVATION 9.61'-5.42'=4.19'
(Instrument midway between pegs)



ADJUSTMENT OF LEVEL (TWO PEG METHOD)
Figure 1.22

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Adjustment of the Level (cont'd)

Wye Level. A Wye Level is in adjustment when:

a. The horizontal cross hair is truly horizontal with the instrument leveled.

b. The line of sight coincides with the axis of the pivots of the telescope or parallel to it.

c. The axis of the spirit level is in the same plane with the line of sight.

d. The axis of the bubble tube and the line of sight are parallel.

e. The axis of the level tube is perpendicular to the vertical axis of the instrument.

The adjustments are made in the following order:

a. Adjustment of the cross hairs.

(1) To make the horizontal cross hair truly horizontal when the instrument is leveled, rotate the cross hair ring as in the case of the transit adjustment previously described, if the instrument is so constructed that the telescope cannot be rotated in the wyes. In many instruments the telescope can be rotated in the wyes while others are equipped with a stop regulated by an adjusting screw, which prevents the telescope from rotating beyond a certain point.

The instrument is leveled and some point found which is on the horizontal cross hair. The telescope is turned slowly about the vertical axis so that the point appears to traverse the field of view. If the point remains on the cross hair, the adjustment is perfect. If it does not, then an adjustment must be made, the manner of doing this depending upon the construction of the instrument. If the telescope cannot be rotated in the wyes, the adjustment is made by rotating the cross hair ring similar to the adjustment described for the transit. If the telescope has a stop screw this must be moved until the instrument satisfies the test. Since there is nothing to hold the telescope rigidly in this position, the adjustment in the last case is likely to be disturbed at any time.

(2) When the above adjustment is completed the line of sight should be made to coincide with the axis of pivots or parallel to it. See Figure 1.23, following.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Wye Level (cont'd)

ADJUSTMENT OF THE CROSS HAIRS
(Second Part)

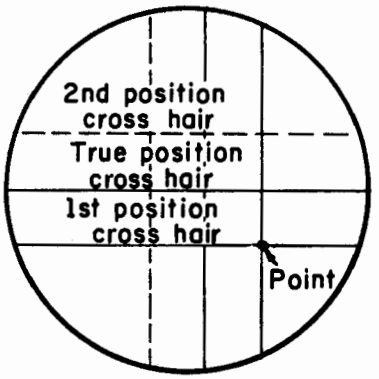


Figure 1.23

Pull out the pins which hold the clips on the telescope and turn the clips back so that the telescope is free to turn in the wyes. Sight the intersection of the cross hairs at some well-defined point, using the leveling screws for the vertical motion and the clamp and tangent screw for the horizontal motion. Then rotate the telescope 180 in the wyes, so that the level tube is above the telescope. The intersection of the cross hairs should still be on the point. If not, move the horizontal cross hair half-way back to its first position by means of the upper and lower adjusting screws of the cross hair ring. Then move the vertical cross hair half-way back to its first position by the other pair of screws. Repeat this test until the adjustment is perfect.

b. Adjustment of the bubble tube (indirect method)

(1) To put the axis of the bubble tube in the same plane with the line of sight, bring the bubble to the center of the tube and rotate the telescope in the wyes for a few degrees (very little is necessary); if the bubble moves toward one end of the tube, that end must be higher, which indicates the direction in which the adjustment should be made. Move the lateral motion screws of the tube until the bubble returns to the center. Test the adjustment by rotating the telescope each way.

(2) To make the axis of the bubble tube and the line of sight parallel to each other, first clamp the instrument, then bring the bubble to the center of the tube, lift the telescope out of the wyes, turn it end for end and set it down in the wyes, the eye end now being where the objective was originally. See Figure 1.24.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Wye Level (cont'd)

ADJUSTMENT OF THE BUBBLE TUBE BY INDIRECT METHOD

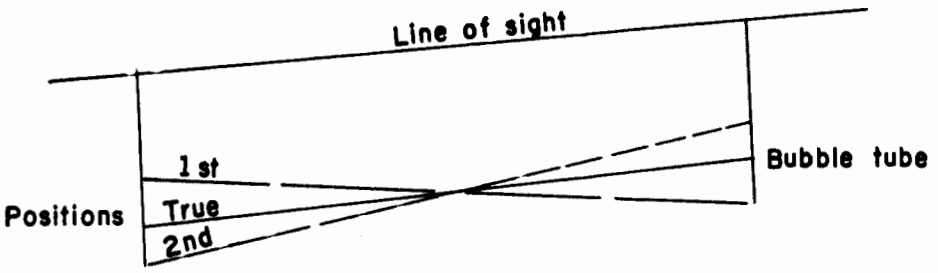


Figure 1.24

This operation must be performed with the greatest care as the slightest jar of the instrument will impair the results. If the bubble returns to the center of the tube, the axis of the tube is in the correct position. If it does not return to the center, the end of the tube provided with the vertical adjustment should be moved until the bubble moves half-way back to the center. This test must be repeated to make sure that the movement is due to defective adjustment and not to the jarring of the instrument.

c. Adjustment of the Wyes.

To make the axis of the bubble tube perpendicular to the vertical axis of the instrument, bring the two clips down over the telescope and fasten them. Level the instrument, bring the bubble precisely to the middle of the tube over one set of leveling screws, and then turn the telescope 180 about the vertical axis. If the bubble moves from the center, bring it half-way back by means of the adjusting screws at the foot of one of the wye supports. See Figure 1.25.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Wye Level (cont'd)

ADJUSTMENT OF THE WYES

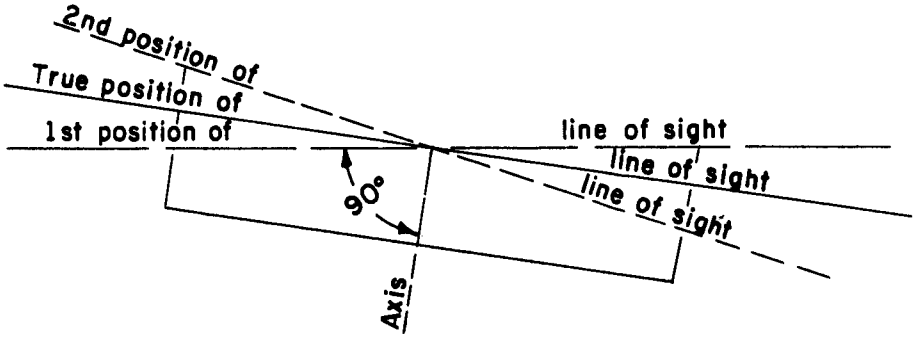


Figure 1.25

Since the bubble is brought to the center of the tube each time a rod-reading is taken, this last adjustment in no way affects the accuracy of the leveling work but is a convenience and a saving of time.

Dumpy Level. A dumpy level is in adjustment when:

a. The horizontal cross hair is truly horizontal with the instrument leveled.

b. The axis of the bubble tube is perpendicular to the vertical axis.

c. The axis of the bubble tube and the line of sight are parallel.

The adjustments are made in the following order:

a. Adjustment of the cross hair. This is made in exactly the same manner as described under Adjustment #2 for the transit.

b. Adjustment of the bubble tube. To make the axis of the bubble tube perpendicular to the vertical axis, it is necessary -- due to the construction of the dumpy level -- to make the adjustment before making the line of sight parallel to the bubble tube. It is done by centering the bubble over one pair of leveling screws, and turning the instrument 180° about the vertical axis. If the bubble does not remain in the center of the tube, move it half-way back to the center by means of the adjusting screws on the level tube.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Dumpy Level (cont'd)

c. Direct or "Peg" adjustment. To make the line of sight parallel to the axis of the bubble, perform the two-peg test. Follow the same procedure as described under Adjustment #5 for the transit, except that instead of adjusting the telescope bubble, raise or lower the horizontal cross hair by means of the cross hair reticule screws until the correct reading is obtained on the far rod.

The two-peg test may also be used when making this adjustment on the wye level, although the indirect method as described under adjustment of the wye level is simpler.

Hand Level. To adjust a hand level hold it alongside an engineer's level that has been leveled and sighted on some well-defined point. The line of sight of the hand level should strike the same point when the bubble is centered.

If the above condition is not satisfied, the adjustment should be made as follows;

Locke Hand Level. Adjust by means of the screw at one end of the level tube, which moves the cross-wire defining the line of sight.

Abney Hand Level. Adjust by raising or lowering one end of the level tube until the bubble is centered, the index having first been set at zero on the graduated arc. The principle of the two-peg method of adjustment as described in this chapter for the engineer's level may also be used.

Adjustment of the Plane Table Alidade.

Adjustments of the telescopic alidade require no additional principles of adjustment that have not been explained as they apply to the transit or level. Survey work done with the plane table and telescopic alidade is not required to be as precise as when the work is done with the transit; therefore, the adjustments need not be as refined.

Since the telescope is not reversed in a vertical arc, no appreciable error is caused because of lack of perpendicularity between the line of sight and the horizontal axis, or through lack or parallelism of the line of sight with the edge of the ruler. It can also be assumed without appreciable error that the edges of the ruler are straight and parallel and that the horizontal axis is parallel to the surface of the ruler.

1. Adjusting the control level so that its axis is parallel to the ruler:
   a. The test and correction is the same as described for adjustment of the plate levels of the transit except that reversing of the plate or ruler is accomplished by carefully marking a guide line on the plane table sheet.
   b. The board is not reversed.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Adjustment of the Plane Table Alidade (cont'd)

2. Adjusting the vertical cross hair so that it lies in a plane perpendicular to the horizontal axis:

a. The test and adjustment is the same as for the transit.

3. Adjusting the telescope level so that its axis is parallel to the line of sight:

a. The test and correction is the same as described for adjustment of the telescope level on the transit.

If the alidade is one in which the telescope can be rotated about its axis in a sleeve, the two adjustments described below under (1) and (2) should be used. These adjustments are practically the same as those described for the corresponding adjustments of the wye level.

(1) Making the line of sight coincide with the axis of the telescope sleeve:

a. In making the test the intersection of the cross hairs should be sighted on some well-defined point and the telescope carefully rotated through 180^{0}. Generally the rotation is limited by a shoulder and lug. If the intersection of the cross hairs stays on the point the line of sight coincides with the axis of the telescope sleeve.

(2) Adjusting the axis of the striding level so that it is parallel to the telescope sleeve and therefore parallel to the line of sight.

In making the test the striding level is placed on the telescope and the bubble is brought to the center of the level tube. The striding level is then carefully removed and turned end for end and replaced on the telescope barrel. If the bubble returns to the center of the tube the level is in adjustment. If the bubble is not centered, it should be brought back one-half of the displacement by means of the adjusting screw on one end of the bubble tube.

The bubble should then be brought to the center by means of the tangent screw and the test repeated.

4. Adjusting the vernier to read zero when the line of sight is horizontal:

a. This adjustment is the same as described for the transit.

b. Adjusting the auxiliary level on the vernier arm so that its axis is parallel to the axis of the telescope when the vernier reads zero.

9. ADJUSTMENT OF INSTRUMENTS (CONT'D)

Adjustment of the Plane Table Alidade (cont'd)

4.b. (cont'd)

The telescope bubble should be brought to the center of its tube and the vernier moved by means of the tangent screw until it reads zero. If the auxiliary level on the vernier arm is not centered, it should be moved by means of the capstan-headed screws until it is in the center of the tube.

10. SURVEY FIELD NOTES

Field notes are the record of a survey with the data recorded in such form that it can be readily interpreted by anyone having a knowledge of surveying. They consist of numerical data, explanatory notes and sketches. They should include the names of the survey party member, date, weather conditions, and a title of the survey giving its location and nature or purpose.

The notes should all be recorded in a field notebook at the time the work is being done. Do not leave anything to the memory or copy from temporary notes. All entries should be clear, concise and legible.

All data pertaining to one survey or project should be entered in the same field book or series of books. Leave sufficient space in the front of each book to permit proper indexing when surveys are completed. If loose leaf notebooks are used for a series of small jobs on an individual farm, each set should have the same information regarding survey party members, date, weather, etc., as previously described. These should be bound and filed so that they can be readily found when needed.

The use of sketches in field notes are very important in conveying the correct impression to others who may use the notes in plotting the data or using it in design of various structures. They should be drawn approximately to scale.

When making surveys for the design of storage, flood control and diversion dams, gully control structures, drainage ditches or stock water dams, the line of direction of the survey must be clearly indicated in the notes.

Form

The form in which notes are recorded varies for the different types of surveys made. However, insofar as possible for each type of survey, a uniform sustem should be prescribed and followed. The notes would then be readily understandable when personnel are transferred from one location to another. Sample forms of field notes for recording data on various types of surveys are shown in the ensuing paragraphs.

10. SURVEY FIELD NOTES (CONT"D)

Indexing.

Indexing of field notebooks will provide an efficient method of locating field data for various surveys. To be of greater value the index should be kept current.

In setting up an index system for field notes the following points are important:

a. Number each field notebook on the right hand page consecutively and show work unit name and address on the inside of the cover.

b. Leave the first two or three pages of the book for indexing of various surveys.

c. Number the pages on one side through the entire book.

d. Set up Master Index Book in alphabetical order.

11. TYPES OF SURVEYS

Differential Leveling

Every construction project of appreciable size requires the establishment of elevations on bench marks of a more or less permanent nature. Elevations for a given locality or project are referred to these bench marks. The U. S. Geological Survey has established bench marks in nearly all major cities in the United States and at scattered points in less populated areas. They are generally bronze caps securely set in stone or concrete with elevations referred to mean sea level. Their primary purpose is to provide control points for topographic mapping. They are, however, also useful as points from which other bench marks may be established for public or private projects. Other government, state and municipal agencies as well as private and public utilities companies have established similar monuments.

When starting a new project, levels are run from either a bench mark of known elevation or one with an assumed elevation. If the project is small a more or less permanent bench mark is selected with a known or assumed elevation, and elevations of the project are referred to it. If the project is large, it is desirable to start from a bench mark of known elevation and establish bench marks at scattered points in desirable locations for future reference.

The operation procedure and field notes used in running a bench level circuit is called differential leveling. It may be considered basic to all systems of leveling work. The beginner should be thoroughly familiar with the basic system. A bench level circuit is run for the purpose of determining the relative elevations of two or more bench marks. The circuit may start from a highway or USGS bench mark or from some point of assumed elevation. A bench level circuit is frequently run as a part of profile or cross

11. TYPES OF SURVEYS (CONT'D)

Differential Leveling (cont'd)

sections level or as a part of a topographic survey. In any event the basic procedure and notes will be the same.

On large projects such as long drainage ditches, large reservoir areas or large areas of topographic mapping, it is desirable to run the bench level circuit separately from all other survey work. If this is not done, and mistakes occur, a great deal of additional work will be required to carry corrections through the survey notes. BENCH LEVELS SHOULD ALWAYS BE "CLOSED" ON THE STARTING POINT. That is, after the last bench mark is set, levels should be run back to the starting point as will be described in the procedure.

Procedure.

a. The level is set up at some convenient point between the starting bench mark and the next bench mark or turning point, but usually not over 300 feet from the starting bench mark. It is difficult to read the level rod at distances over 300 feet. A little practice will reveal what should be the limiting distance for the particular level being used.

b. The instrument man begins his field notes by recording the following information. See Figure 1.27.

(1) Location of survey, including name of project, farm or farmer and the legal description of the quarter-quarter section in which the starting point of the survey is located.
(2) Type of survey such as "bench level circuit", profile and cross section drain, or similar description.
(3) Kind of practice and purpose of survey, (Design, construction, etc.)
(4) Farm number, field number and ACP identification (when applicable)
(5) Weather conditions.
(6) Name of surveyors.
(7) Date of survey.
(8) Column headings on left-hand sheet.
(9) Description of starting bench mark. Include reference to the field book in which the elevation of the bench mark was originally recorded. If it is a new bench mark with an assumed elevation, no such notation need be made; however, this assumed elevation should be in even feet, as 100.00 or 200.00 feet.

c. With the rodman holding the rod on the bench mark, the instrument man observes the rod reading and records it in the B.S. + (back sight) column opposite the station (Sta.)BM 1. Referring to Figures 1.26 and

11. TYPES OF SURVEYS (CONT'D)

Procedure c. (cont'd) 1.27 respectively, it will be noted that the backsight on BM1 was 6.82 feet. This reading, added to 144.62 (elevation of BM1) recorded in beginning the field notes, gives 151.44, the HI, (Height of Instrument) or elevation of the line of sight.

d. The rodman then moves ahead and picks out a convenient point for a turning point, or drives his hand axe into the ground for this purpose. The instrument man turns the telescope and takes a rod reading on this turning point. He records this reading in the foresight (FS) column opposite turning point (TP) 1. In Figures 1.26 and 1.27 the foresight for TP 1 was 5.17 feet. This reading substracted from the HI, 151.44, gives 146.27, the elevation of the turning point.

METHOD-DIFFERENTIAL LEVELING

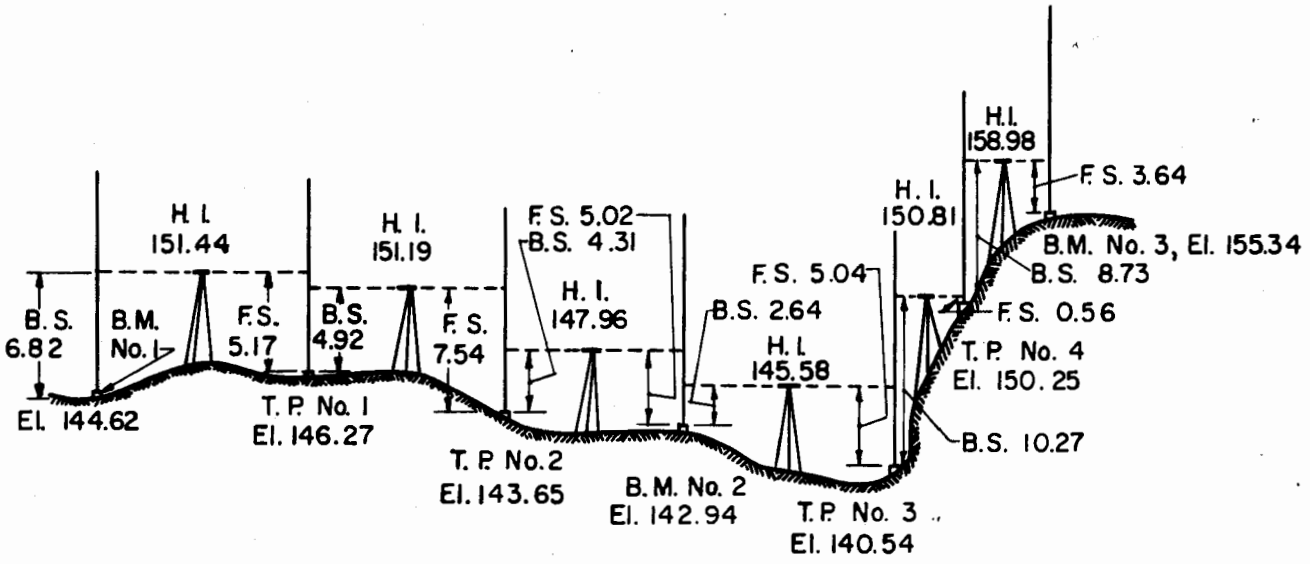


Figure 1.26

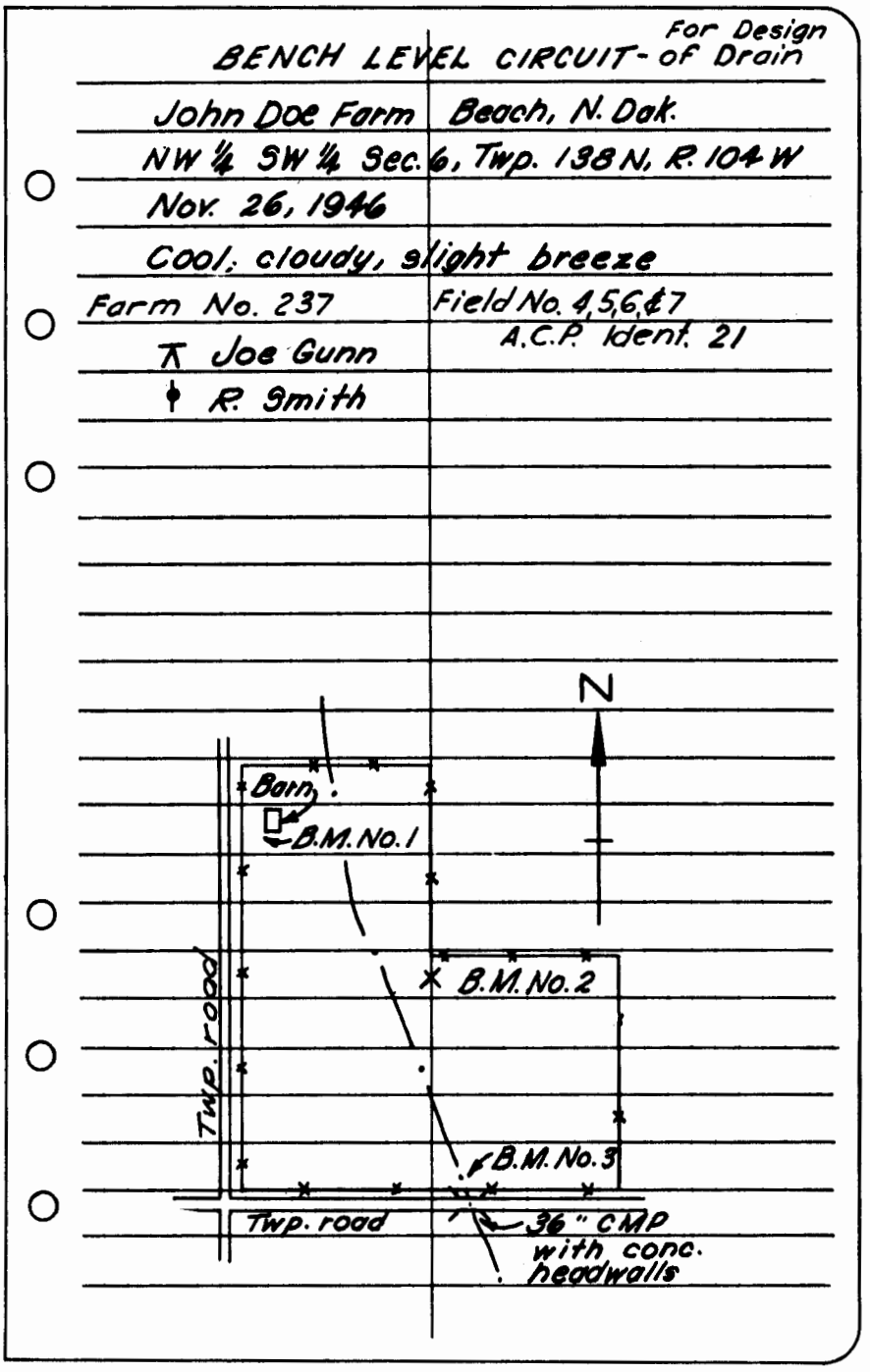

BENCH LEVEL CIRCUIT - For Design of Drain
John Doe Farm
Beach, N. Dak.
NW ¼ SW ¼ Sec. 6, Twp. 138 N, R. 104 W
Nov. 26, 1946
Cool; cloudy, slight breeze
Farm No. 237
Field No. 4, 5, 6, & 7
A.C.P. Ident. 21
Joe Gunn
R. Smith
N
Barn
B.M. No. 1
B.M. No. 2
B.M. No. 3
Twp. road
Twp. road
36" CMP with conc. headwalls

Figure 1.27 - 1

Sta.	B.S.(+)	H.I.	F.S.(-)	Elev.
B.M.No.1	6.82	151.44		144.62
T.P. 1	4.92	151.19	5.17	146.27
T.P. 2	4.31	147.96	7.54	143.65
B.M.No.2	2.64	145.58	5.02	142.94
T.P. 3	10.27	150.81	5.04	140.54
T.P. 4	8.73	158.98	0.56	150.25
B.M.No.3	3.02	158.36	3.64	155.34
T.P. 5	1.27	151.47	8.16	150.20
T.P. 6	7.57	148.48	10.56	140.91
B.M.No.2	5.16	148.11	5.53	142.95
T.P. 7	6.63	149.53	5.21	142.90
T.P. 8	4.93	149.24	5.22	144.31
B.M.No.1			4.60	144.64
				144.62
			Closure	+0.02
	+ 66.27			
	- 66.25			
	+ 0.02			

John Doe B.M.	Circuit for Drain (1)
Cross cut on top of foundation SW. cor. of barn - John Doe farm (see page 6, Field Book No. 3, Golden Valley SCD)	
B.M. No. 2, - Spike in base S side of 12" cottonwood tree 200' south of fence corner.	
B.M. No. 3 - Cross cut on top of NE cor. of culvert conc. headwall under Twp. road 1400'	east of SW corner, Sec. 6, Twp. 138 N, R. 104 W.

SURVEY NOTES - DIFFERENTIAL LEVELING
Figure 1.27 - 2

11. TYPES OF SURVEYS (CONT'D)

Procedure (cont'd)

e. The instrument man then picks up the level, moves ahead, and goes through the same process described above, taking a backsight on TP 1, and a foresight on a new turning point ahead. A word of caution is appropriate at this point; if the survey is to be reasonably precise, each foresight distance should be balanced against the preceding backsight distance to nullify instrumental errors.

f. After the elevation of the last bench mark has been determined, the survey party runs levels back to the starting bench mark in order to "close" the circuit. Referring to Figure 1.27, it will be noted that the foresight on BM3, the last BM in the circuit, was 3.64, giving an elevation of 155.34 for BM3. It will also be noted that the backsight on BM 3 was 3.02 feet. This indicates that after taking the foresight on BM3 and computing the elevation, the level was pulled up and reset in a different place. The level should always be pulled up and reset before starting to run the closing levels back to the starting bench mark. Levels are then run back to the starting bench mark following the same procedure used in running out the original circuit. Note that in a bench level circuit bench marks should always be used as a turning point.

g. After taking the final foresight on the starting bench mark, the "error of closure" can be determined. This is the difference between the actual elevation of the bench mark and the elevation computed from the final foresight. Referring to Figure 1.27, it will be noted that the elevation computed from the final foresight was 0.02 feet too high or +0.02 feet.

Precision. Precision of differential leveling depends on more factors than any other operation of surveying. It depends upon the skill and care of the leveler and the degree of refinement with which the work is done. It is also influenced by the instrument employed. For a given length of line and other conditions remaining equal the error will tend to vary as the number of setups above a certain minimum; therefore, the precision would be expected to be lower in hilly country where the sight distances are limited than it would be in flat country where normal backsight and foresight distances can be used. However, above a certain length of sight the error in reading the rod increases rapidly with the distance, so the precision will be less for long sights than for those of normal length. Erroneous length of rod, unequal refraction and other causes also affects the precision of leveling more between two points at or near the same elevation than it does if the two points have a large difference in elevation, even though the distances are the same.

Since conditions are so variable, no hard and fast rule can be laid down as to the precision that should be attained. Practice indicates that under average conditions, with a level in good adjustment, the error may be kept within the limits prescribed below.

a. Rough leveling for rapid reconnaissance or preliminary surveys. Rod readings to tenths and no particular attention paid to balancing backsight and foresight distances. Maximum error in feet $\pm 0.4\sqrt{\text{distance in miles}}$

11. TYPES OF SURVEYS (CONT'D)

Precision (cont'd)

b. Ordinary leveling such as is needed for the construction of roads, railroads and most other engineering works. Rod read to hundredths. Solid objects used for turning points. Backsight and foresight distances roughly balanced. Sights up to 500 feet. Maximum error in feet $\pm 0.1\sqrt{\text{distance in miles}}$.

c. Accurate leveling for important or principal bench marks on extensive surveys. Sights up to 300 feet. Rod read to thousandths either with target or self-reading rod. Backsight and foresight distances approximately balanced between bench marks and determined by pacing. Bubble centered carefully before each rod reading. Rod waved for large readings. Good turning points such as metal pins or well-defined points on solid objects. Tripod on firm ground. Maximum error in feet. $\pm 0.05\sqrt{\text{distance in miles}}$.

d. Precise leveling requires many more precautions and will not be described; however, the maximum error in feet should not exceed $\pm 0.02\sqrt{\text{distance in miles}}$

In the previous description of differential leveling it will be noted that the elevation computed from the final foresight was 0.02 feet too high or -0.02 feet. The length of the circuit is approximately 1 mile; using the formula for accurate leveling, we find the permissible error = $\pm 0.05\sqrt{1} = 0.05$. The actual error is 0.02 which is less than that permitted. Level note computations should be checked by adding the backsight and foresight columns as shown in Figure 1.27. The difference should equal the error of closure and should be in the same direction - that is, plus or minus. This check merely proves the accuracy of the addition and subtraction performed in the notes. If the foresights and backsights do not check, it will be necessary to recheck the computation of elevations and heights of instrument until the mistake is found.

Profiles and Cross Sections. The object of profile leveling is to determine the elevations of the ground at known distances apart and along a selected or predetermined line. These elevations can then be plotted on profile paper at selected scales so that studies can be made relating to grades, depths, high and low spots, and estimating of quantities of cuts and fills. Cross-sections are simply profiles taken at right angles to a predetermined base line such as the centerline of a road, ditch, gully or other arbitrarily selected base line. Cross sections may be run in conjunction with profile levels, or they may be run after the profile line has been staked and profiles taken.

On many engineering projects it is customary to stake out a line with a transit and tape before running the levels for profile and cross sections. The transit line may be the centerline of a drainage ditch, dam, or irrigation ditch, or an offset line. It may be a continuous straight line, a broken line, or a curved line. The procedure for running traverse surveys will be explained in more detail in the ensuing chapters.

11. TYPES OF SURVEYS (CONT'D)

Profiles and Cross Sections (cont'd)

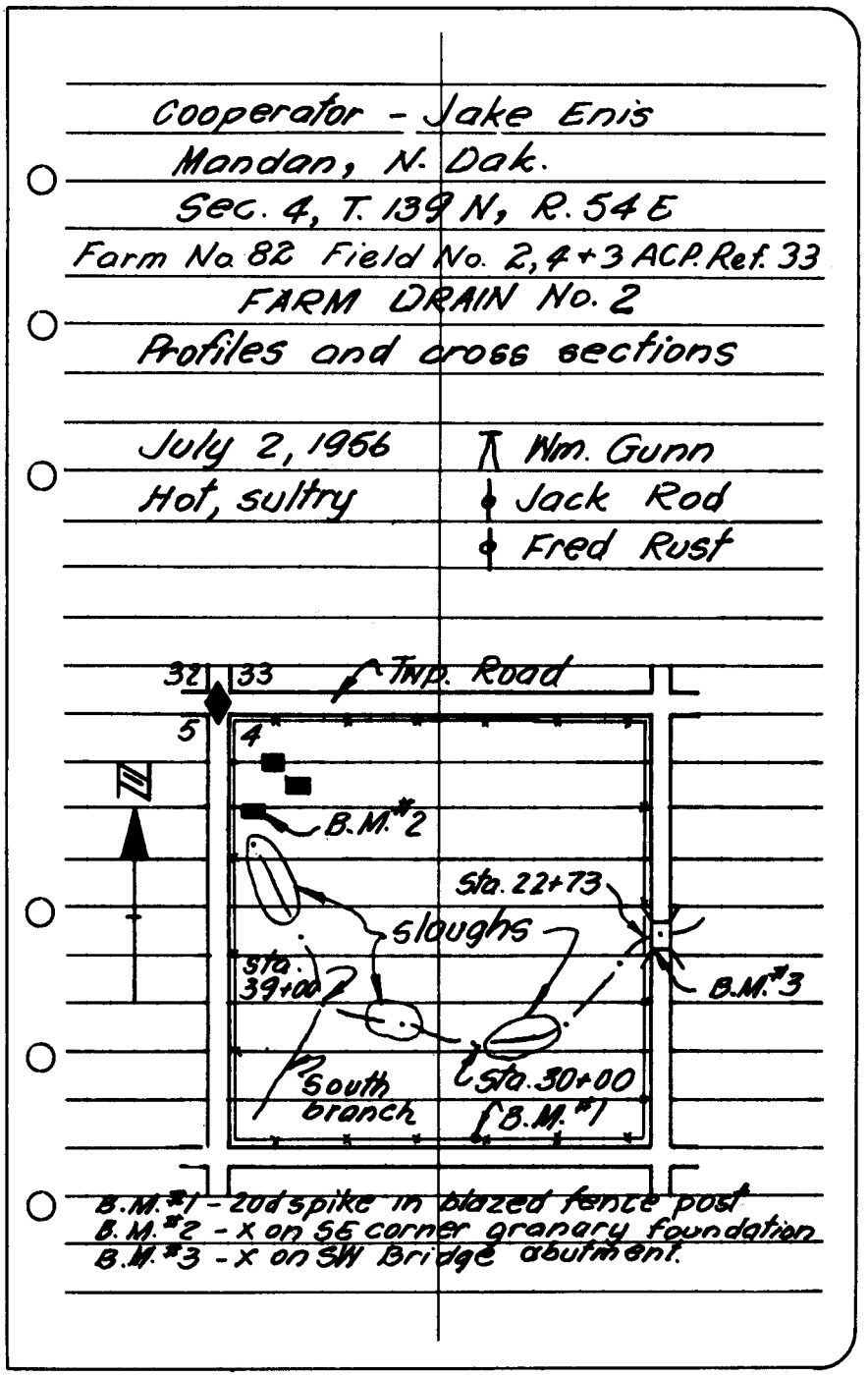
a. The procedure in running a profile, and recording field notes, is essentially the same as in running bench levels, except that rod readings are taken on the ground at field stations and at major breaks in slope between stations. Distances between readings are measured and recorded by full or plus stations. Normally, a line on which a profile is to be run is located and stationed before or during the time profile levels are taken.

b. Wherever possible, set a bench mark near the starting point stake. If this cannot be done, it will be necessary to run levels from the nearest bench mark to the starting point. Location of the starting point stake is described in the notes so that it can be relocated if it is pulled out or otherwise lost. The start of the profile should be at a full station. It may be 0 + 00 or any other selected full station. Frequently, it is desirable to use a higher station as 10 + 00 or 20 + 00 where it is anticipated that it may be necessary to run the profile both ways from the starting point. This is done in order to avoid having to record minus stationing, which is always confusing. Normally the starting station for surveys involving streams, waterways, irrigation canals or ditches and gullies should be located at the upstream end and proceed in the direction of flow. In some cases however, topography and the system to be surveyed might be such that the survey work could be accomplished with less time and effort by locating the starting point at the downstream end and proceeding upstream. This is especially true for drainage surveys. In all surveys which might involve computations for water surface profiles the stationing numbering should proceed progressively downstream. The sample field survey notes, Figure 1.28, illustrate the use of a station other than 0+00 for the starting point. In this case, the survey party started at station 20+00, ran the profile back to station 9+00, then started again at station 20+00 and ran the profile down to station 29+00.

c. After establishing a starting point, the instrument man sets up the level and reads a backsight on the benchmark and determines the HI. He then observes a rod reading with the rod held on the ground at the starting point. He gives a ground rod reading at each full station and at such plus stations as are necessary. Ground rod readings are taken to the nearest 0.1 foot and ground elevations are computed only to the nearest 0.1 foot.

d. When the rodman has moved along until he is about 300 to 350 feet away from the instrument, a TP is taken on a solid object. The instrument man then moves ahead, sets up, takes a backsight on TP, computes a new HI, and continues as before. Rod readings and elevations on TPs and BMs should be read and recorded to 0.01 foot, but in computing ground elevations use the HI only to the nearest 0.1 foot.

e. If a transit line has not been previously run and recorded, a sketch should be drawn in the field book to indicate changes in direction of the profile and its relationship to nearby landmarks. Plus stations should always be measured and recorded at all important points along the profile line, such as at branch ditches, tile laterals, gullies, gully overfalls, culverts,



PROFILE AND CROSS SECTION NOTES
Figure 1.28-1

Sta.	B.S.	H.I.	F.S.	Elev.
B.M.#1	1.34	501.34		500.00
30+00				
30+50				
31+00				
31+50				
32+00				
33+00				
34+00				
35+00				
36+00				
T.P.#1	9.76	509.22	1.88	499.46
37+00				
38+00				

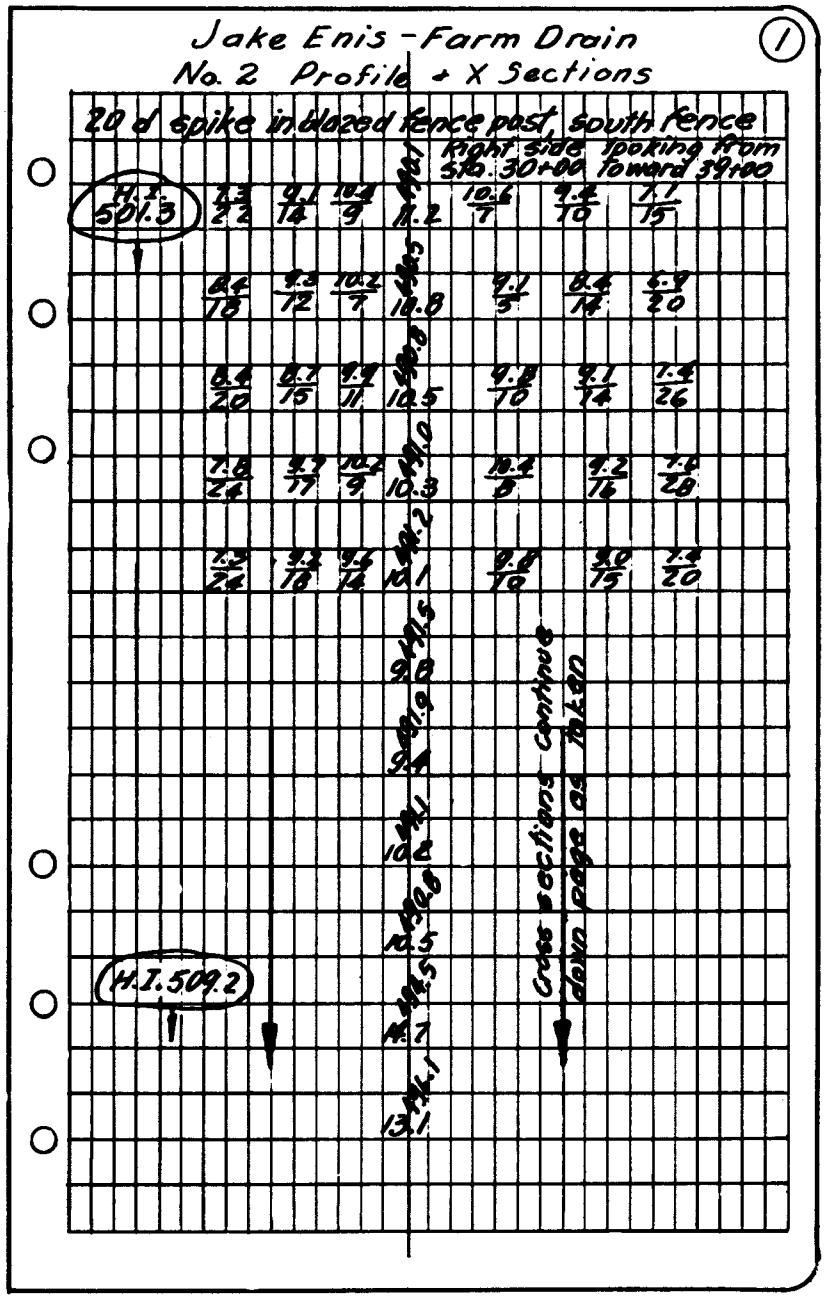
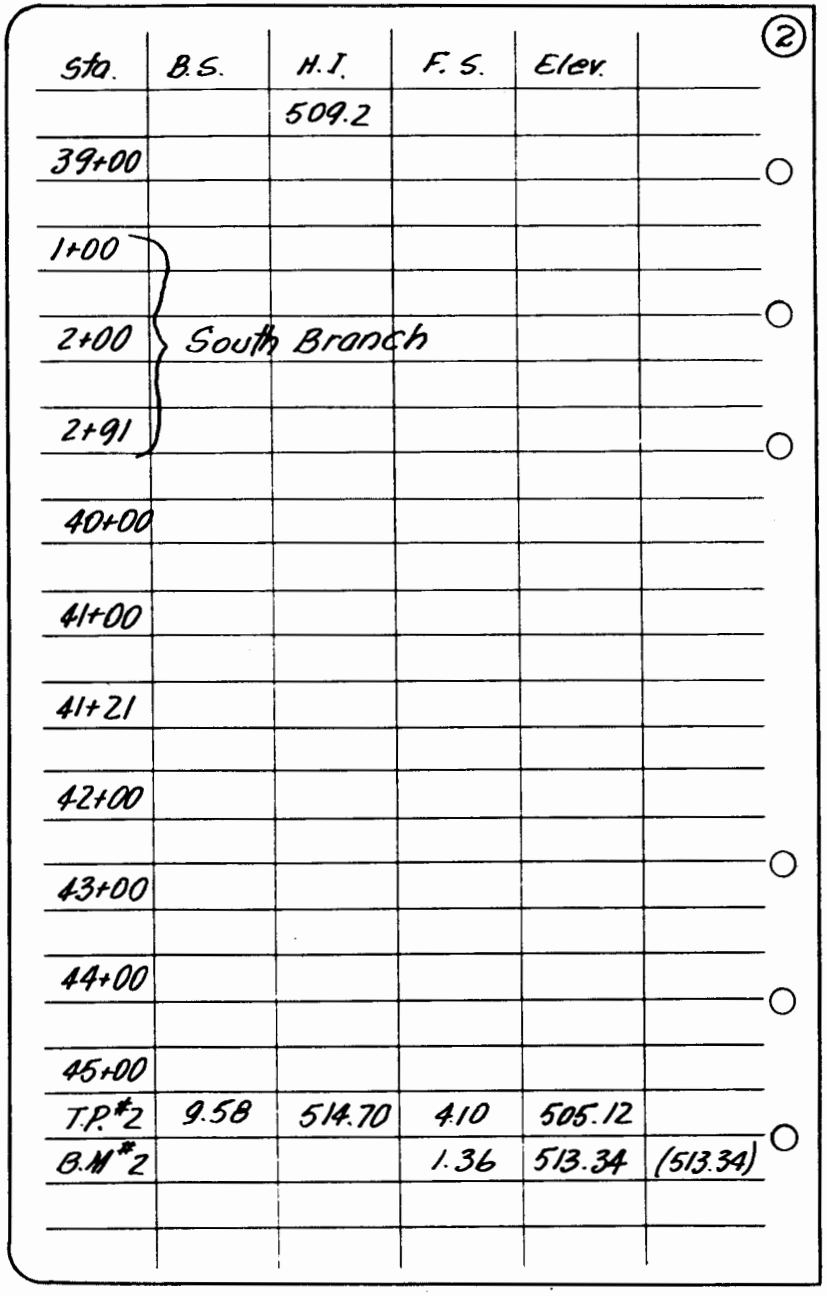

Jake Enis - Farm Drain
No. 2 Profile & X Sections
20 d spike in blazed fence post, south fence
right side looking from Sta. 30+00 toward 39+00
H.I. 501.3
H.I. 509.2
Cross sections continue down page at 38+50

Figure 1.28-2



Sta.	B.S.	H.I.	F.S.	Elev.	
		509.2			
39+00					
1+00					
2+00	South Branch				
2+91					
40+00					
41+00					
41+21					
42+00					
43+00					
44+00					
45+00					
T.P.#2	9.58	514.70	4.10	505.12	
B.M.#2			1.36	513.34	(513.34)

Figure 1.28-3

Sta.	B.S.	H.I.	F.S.	Elev.	(3)
B.M.#1	0.87	500.87		500.00	
29+00					
28+00					
27+00					
26+00					
25+00					
24+00					
23+00					
22+73	West end of bridge				
B.M.#3			9.82	491.05	(491.04)

Jake Enis Farm Drain No.2 Profile + X Sections (3)
July 6, 1956 π Fred Rust ϕ Albright ϕ Gunn
Cool + Cloudy

20 d spike in blazed fence post

X on S.W. bridge abutment

Figure 1.28-4

11. TYPES OF SURVEYS (CONT'D)

Profiles and Cross Sections (cont'd)

bridges, roads, fence lines, headgates or takeouts, drops, checks, and similar features. It is useful to have this information in studying the profile and later in staking construction works on the ground.

f. Frequently it will be desirable to set a hub stake (2"x2"x16" stake driven flush with the ground) every 500 feet or less in order to "tie in" or relate other survey work to the profile.

g. The sample survey notes (Figure 1.28) indicate the method of recording cross-section notes when cross sections are run at the same time as the profile. Stations are selected as shown in Figure 1.28 at which it is desired to obtain cross sections. The stationed line or transit line is used as the base line from which measurements are taken to both sides at right angles to the base line. Sometimes an offset line is used and cross sections are taken only to one side or both sides as is deemed necessary to obtain the information desired. A rod reading is taken on the stationed line at the station and recorded on the right-hand page opposite the appropriate station. For example, station 30+00, Figure 1.28. Since this reading was taken on the base line, it is recorded as 11.2 and recorded directly on the centerline of the right-hand sheet of the field book. The rodman then moves out at right angles to the base line with the rod and one end of the tape to the first major break in ground slope. The rear chainman stands at the base line, reads and calls off the distance from this point to the rodman. The instrument man reads the rod and records the distance and rod reading either to the right or left of the centerline of the right-hand sheet, depending on which side of the line the shot was taken. The rod reading and distance are recorded as follows: $\frac{10.6}{7}$ the top number being the rod reading and the bottom number the distance. The process is continued until the cross section is run out as far as necessary in one direction. The rodman then returns to the base line and a similar process is repeated in the opposite direction. Elevations along the cross section line are generally not computed in the field unless they will be plotted in the field. This work is usually done in the office.

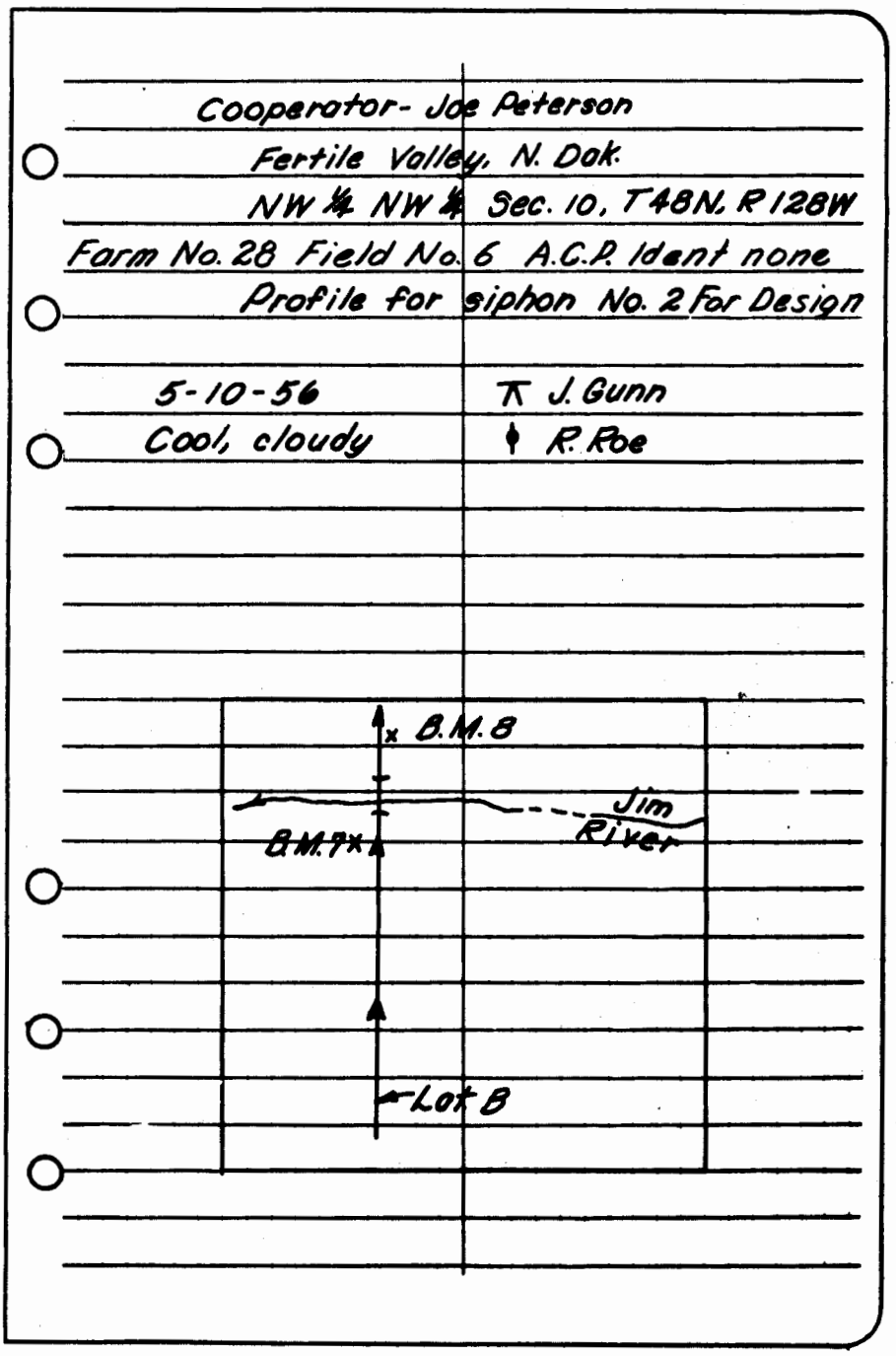
h. It is not essential that the zero of the cross section be the centerline of the gully, ditch or stream. In some cases, the profile line may be along the bank of a ditch. In any case, the zero of the cross section is on the base line.

It is essential that the instrument man indicate in the field notes the direction of the cross section in such a manner that it will be clear to him or to a draftsman in the office. On ditch, gully or stream cross sections, it is standard practice to refer to "right" and "left" bank, when facing downstream. Where a cross section is taken at a proposed structure site it should be located so that this line may be reproduced later if required. This can be done by setting a hub stake at the zero point of the cross section and one or more additional stakes on the cross section line 30 to 100 feet from the zero point. These stakes should be driven nearly flush with the ground so they will not be disturbed.

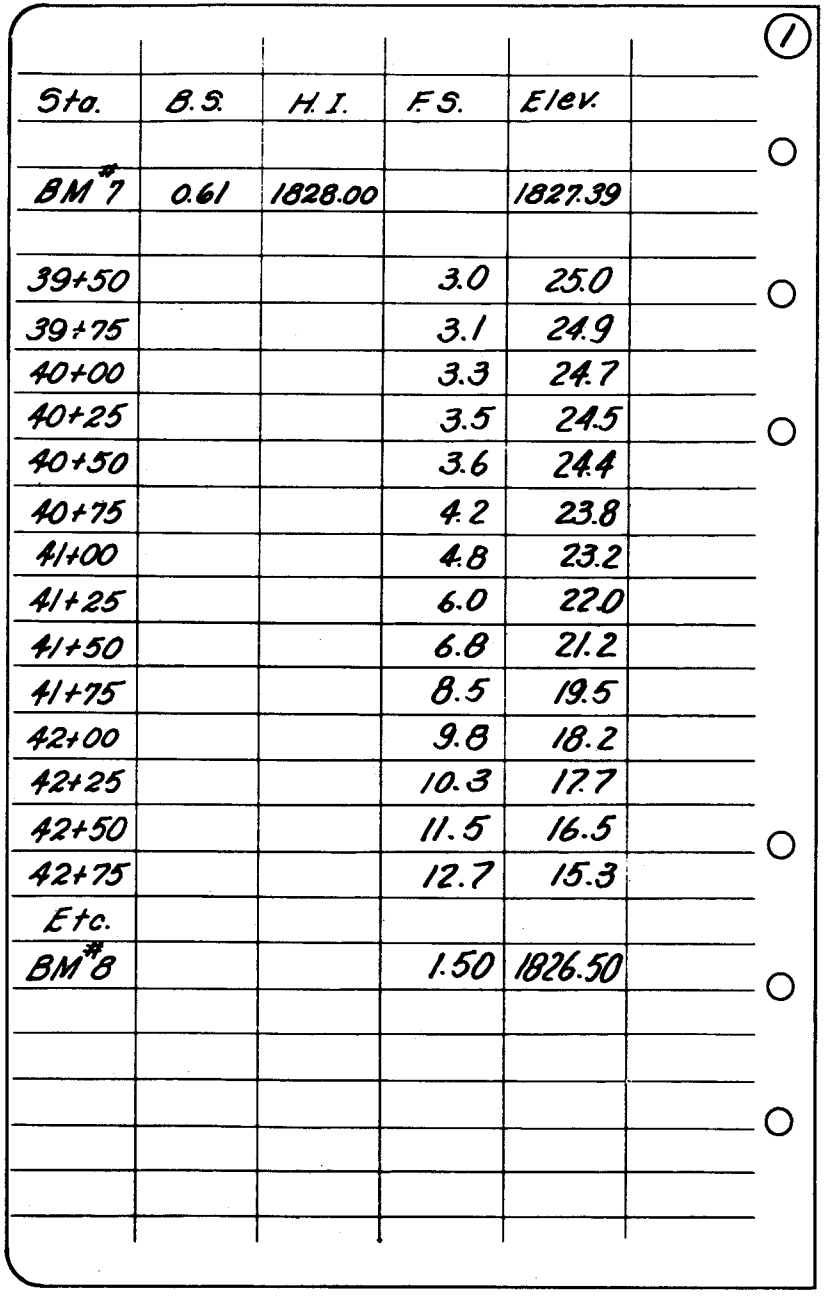
11. TYPES OF SURVEYS (CONT'D)

Profiles and Cross Sections (cont'd)

i. Cross sections are generally taken to compute volume or quantities of material. Sometimes they are taken to study the hydraulic characteristics of gullies, streams, or other meandering watercourses. They do not provide a very satisfactory method on constructing a topographic sketch. For methods of topographic mapping, see Topographic Surveys under Types of Surveys.



PROFILE AND CROSS SECTION NOTES
Figure 1.29-1



Sta.	B.S.	H.I.	F.S.	Elev.
BM #7	0.61	1828.00		1827.39
39+50			3.0	25.0
39+75			3.1	24.9
40+00			3.3	24.7
40+25			3.5	24.5
40+50			3.6	24.4
40+75			4.2	23.8
41+00			4.8	23.2
41+25			6.0	22.0
41+50			6.8	21.2
41+75			8.5	19.5
42+00			9.8	18.2
42+25			10.3	17.7
42+50			11.5	16.5
42+75			12.7	15.3
Etc.				
BM #8			1.50	1826.50

Figure 1.29-2

11. TYPES OF SURVEYS (CONT'D)

Vertical Curves

Many times it is desirable to employ use of the vertical curve when laying short sections of pipe line, siphon or other structures which may change direction in a vertical plane. Usually the vertical curve is an arc of a parabola and is well adapted to produce a gradual change in direction.

The following field notes and example problem will illustrate one method of determining elevations along a vertical curve and the placing of pipe at the curve elevation or at some other desired location.

The notes in figure 1.29 show elevations at each 25 feet of stationing along the proposed centerline of the pipe. (See profiles and cross sections) These elevations are plotted on cross-section paper and the tangents to the vertical curve are then laid in. See figure 1.30. The choice of tangent line location may be influenced by depth of cut, rate of change of the curve, inlet or outlet conditions and length of curve, as well as the character of the pipe that will be installed. Each individual case should be investigated for the most economical design.

Example: It is desired to lay an 18 inch siphon pipe down the ground slope shown in figure 1.30. A maximum cut of 3 feet can be permitted.

Required:

1. Elevations every 25 feet for invert of pipe and depth of cut at each station.

Solution:

1. Draw ground surface profile of centerline on cross-section paper.
2. Lay in tangent AV to curve and project line AV to D. (AV=VD). Drop vertical line from point D to point B. Draw tangent VB.
3. Calculate elevations for each 25 foot station on the tangents.
   Tangent AV:
   Length = 125 feet
   Difference in elevation between points A and V = 25.0 - 24.5 = 0.5 foot.
   Drop in grade from point A to point V by 25 foot stations is $\frac{0.5}{5} = 0.1$ foot
   Similarly for tangent VB:
   Difference in elevation from point V to B = 24.5' - 18.0' = 6.5 feet
   The drop in grade between each 25 foot station is = $\frac{6.5}{5} = 1.3'$
4. Draw long chord AB.
   Elevation of midpoint, C, of long chord is
   $\frac{\text{elev a + elev B}}{2} = \frac{25.0 + 18.0}{2} = 21.5'$

11. TYPES OF SURVEYS (CONT'D)

Vertical Curves-Solution-4 (cont'd)

The midpoint of the vertical curve is midway between the vertex V and the midpoint of the long chord, C.

$$\text{Elevation of midpoint of curve} = \frac{24.5 + 21.5}{2} = 23.0 \text{ feet}$$

The tangent offset distances from the tangents to the curve may now be computed by employing the property of the parabola in which the tangent offset varies as the square of the distance from the tangent point. These distances may then be subtracted from the tangent point elevation at each station to obtain the curve elevations.

The offset from the vertex, V, to the curve is 24.5 - 23.0 = 1.5 feet.

The tangent offsets from stations 40+50 and 41+00 is

$$\frac{(100)^2}{(125)^2} \times 1.5' = 0.96'$$

The tangent offsets from stations 40+25 and 41+25 is

$$\frac{(75)^2}{(125)^2} \times 1.5' = 0.54'$$

The tangent offsets from stations 40+00 and 41+50 is

$$\frac{(50)^2}{(125)^2} \times 1.5' = 0.24'$$

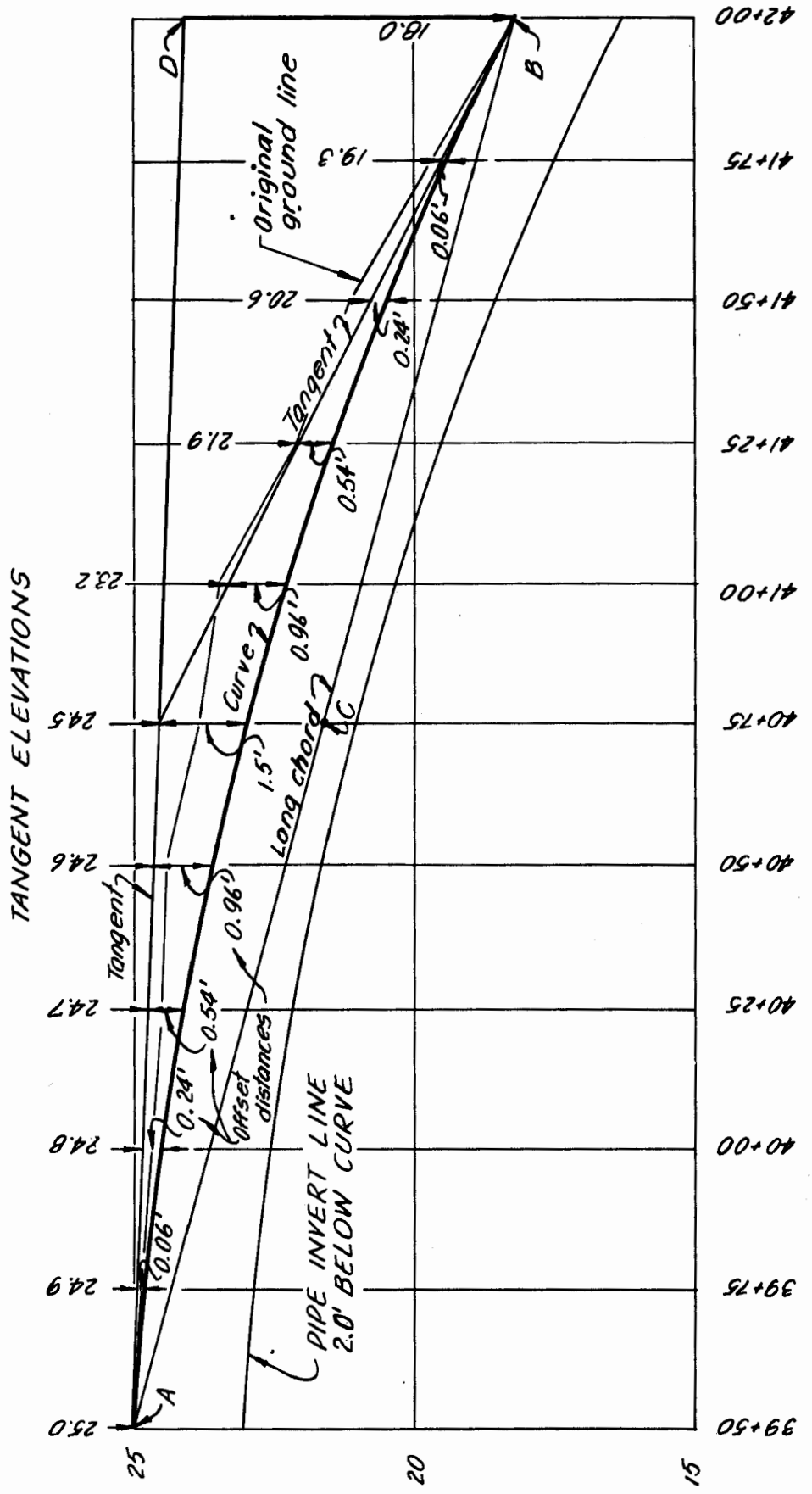
The tangent offsets from stations 39+75 and 41+75 is

$$\frac{(25)^2}{(125)^2} \times 1.5' = 0.06'$$

These offsets may be plotted, the curve drawn, and elevations established for points on the curve. See Figure 1.31.

The pipe invert elevations may also be determined for each 25 feet station when it is desired that the pipe should be set at some place other than on the curve line.

In figure 1.31 the pipe invert was placed 2.0 feet below curve line.



SAMPLE VERTICAL CURVE

Figure 1.30

11. TYPES OF SURVEYS (CONT'D)

Vertical Curves, (cont'd)

TABULATION OF VERTICAL CURVE DATA

Station	Elev. of Tangent	Offset Feet	Elev. of Curve	Elev. of pipe Invert-2.0' Below Curve Line	Ground Elev.	Cut Ft.
39+50 = A	25.0	0	25.0	23.0	25.0	2.0
39+75	24.9	0.06	24.84	22.84	24.9	2.1
40+00	24.8	0.24	24.56	22.56	24.7	2.1
40+25	24.7	0.54	24.16	22.16	24.5	2.3
40+50	24.6	0.96	23.64	21.64	24.4	2.8
40+75 = V	24.5	1.50	23.00	21.00	23.8	2.8
41+00	23.2	0.96	22.24	20.24	23.2	3.0*
41+25	21.9	0.54	21.36	19.36	22.0	2.6
41+50	20.6	0.24	20.36	18.36	21.2	2.8
41+75	19.3	0.06	19.24	17.24	19.5	2.3
42+00 = B	18.0	0	18.0	16.00	18.2	2.2

* Maximum Cut

Figure 1.31

Traverse or Route Surveys

A traverse survey consists of a series of connected lines, of which the lengths, and angles between them, have been determined by measurement. There are two kinds of traverses, (1) the closed traverse and (2) the open traverse.

A closed traverse is one which starts at some point, makes a circuit and eventually returns to the beginning point. A survey of the boundaries of a parcel of land is an example of this type of traverse.

The open traverse does not return to the point of beginning. Examples of this type of traverse are route surveys, for highways, railroads, large drainage ditches, etc. For point of beginning of irrigation or drainage surveys see paragraph b under Profiles and Cross Sections. In its simplest form no checks by calculations can be made; however, if such a traverse starts and ends on points of which the coordinates are known some sort of check can be made because it will in fact constitute a closed traverse.

It is customary in closed traverses to record the length of each line that is the distance from angle point to angle point. However, in route surveys or open traverse the line is measured continuously from the starting point to the end of the line. (See chaining for manner of stationing the line).

11. TYPES OF SURVEYS (CONT'D)

Traverse or Route Surveys (cont'd)

Angles are measured with the transit. Checks are made by doubling the angles or by repeating a sufficient number of times to secure the desired precision. Angles are measured in several ways, (1) by turning to the right, (2) measurement of the interior angles, (3) measurement of the deflection angles, (4) measurement of the Azimuths.

Important points or stations should be "tied in" so that they may be readily found or replaced. Not less than three horizontal measurements to the nearest 0.01 foot should be taken from readily identifiable permanent points to the station. The measurements should be carefully recorded by means of a sketch as in Figure 1.32 below.

TIES TO TRAVERSE STATION

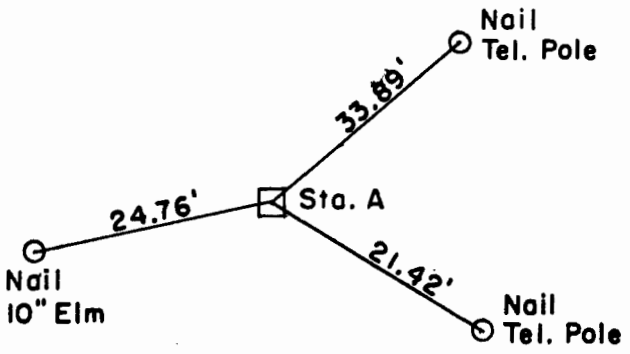


Figure 1.32

Procedure. In making a survey with the transit, the field work can ordinarily be divided into (1) the establishment of the transit stations and transit lines by angular and linear measurements, and (2) the location of objects and points with respect to the transit line. The transit line forms the skeleton of the survey and is referred to as the horizontal control; measurements taken to locate objects or establish points furnish the details for the survey. For some surveys the detail secured is little; surveys to establish the boundaries of land where the transit stations are usually at the corner, and if the boundaries are straight require a few measurements of detail.

On other surveys the location of features away from the transit line is the greatest part of the work. For example, in topographic surveying every transit station may have many points to which measurements are taken to obtain adequate information for construction of the map. Sometimes the collection of details is taken as the work of laying out the transit line proceeds; for others the details are obtained after the transit line has been established and checked. If the survey covers a large territory, the latter procedure is most likely to be used.

The object of the survey is either (1) to locate certain features of the landscape, or (2) to establish points and lines with respect to length and direction so that they can be used as a guide for future work.

11. TYPES OF SURVEYS (CONT'D)

Procedure (cont'd)

The procedure used to run a transit traverse is much the same for one type of traverse as for another. Since most traverse surveys connected with Soil Conservation work consist of establishing a route and since the deflection-angle traverse is the one most commonly used for this purpose, it will be explained in detail. Another type of transit traverse will be described under Topographic Surveys.

Deflection Angle Traverse. The deflection angle traverse provides a means of locating points for either a closed or continuous traverse. This type of survey is widely used and is adaptable to obtaining of detail and topography, but is generally employed for location of roads, canals, center-lines and boundaries.

A deflection angle is the angle between a line and the extension or prolongation of the preceding line.

DEFLECTION ANGLES

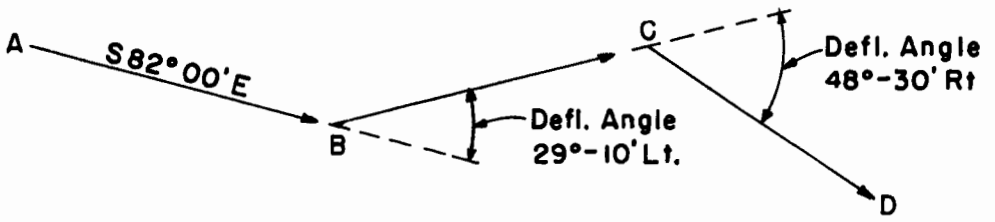


Figure 1.33

Deflection angles are recorded as right or left. In Figure 1.33 the angle at B is 29° - 10' left because the angle was measured counter-clockwise from the prolongation of the preceeding line (A-B). The angle at C is 48° - 30' right because the angle was measured clockwise from the extension of line B-C.

This method an angular measurement readily lends itself to the calculation of bearings if one of the lines is known.

In Figure 1.33, the bearing of line A-B is given as S 82°E. Therefore, the bearing of line B-C is 180° - 82° - (29° - 10') = N 68° 50'E. The bearing of line C-D would be 180° - (68° - 50') - (48° - 30') = S 62° 40'E.

Procedure for taking deflection angles; (See examples of deflection angle traverses, Figures 1.34, 1.48 and 1.49.

a. Set transit on point E and set index of vernier at 0° . (See Figure 1.34).

11. TYPES OF SURVEYS (CONT'D)

Deflection Angle Traverse (cont'd)

b. With lower clamp loose, sight on point D and tighten clamp. With lower slow motion screw, sight point D exactly. (Telescope is direct).

c. Reverse telescope, loosen upper clamp and rotate transit about its vertical axis in the direction (to the left) of point F. Tighten upper clamp and by means of tangent screw sight point F exactly. The angle is then read and recorded. (62° - 00' LT)

d. Leaving telescope in reversed position, loosen lower clamp and rotate transit about vertical axis and sight point D again by use of tangent screw and lower clamp.

e. Rotate telescope (now in direct position) and turn angle (to the left) and sight point F by means of upper clamp and tangent screw. The angle has now been doubled (123° - 30' LT) and one-half of the total recording is the correct deflection angle to use.

Example: (Figure 1.34, point E)

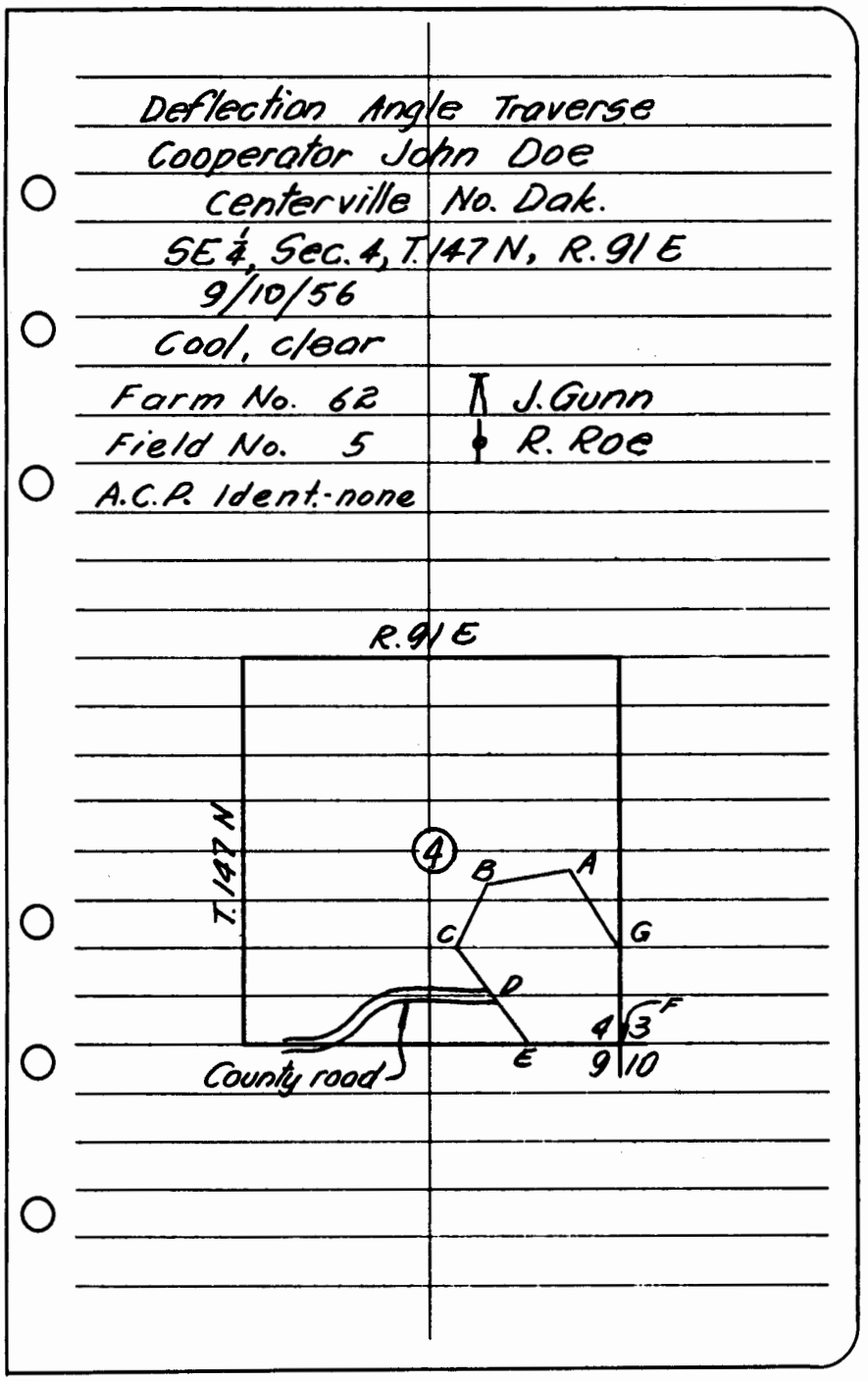
1st angle = 62° - 00' LT
Double angle = 123° - 30' LT
The mean deflection angle is 61° - 45' LT

f. Deflection angles are obtained in this manner for each point around the traverse.

g. Establishing distances between traverse points may be done by (A) stadia or (B) chaining. When more accuracy is required the use of the chain is recommended. The transit is used to keep chainman on line and to obtain any vertical angles necessary to correct inclined distances to true horizontal.

The notes illustrated in Figure 1.34, show a method of running a deflection angle traverse (closed). This type of notes may be used when a deflection angle traverse is made for determining location and route of canals, ditches, roads and pipe lines. This is the continuous or open type survey where stakes are set at 100 foot stations. (See Figure 1.51)

The center line of the right hand page represents the traverse. The notes are kept up the page and items noted in the sketch should be opposite to the stationing shown on the left hand page.



NOTES - DEFLECTION ANGLE TRAVERSE
Figure 1.34-1

Sta.	Def. ∠	2 x Def. ∠	Dist
G			
A	75°30' Lt	151°00'	
			590.75
B	47°00 Lt	94°30'	
			600.12
C	61°30' Lt	123°00'	
			503.20
D	0°00'	0°00'	
			418.07
E	62°00' Lt	123°30'	
			755.10
F	Etc.		
G			
A			

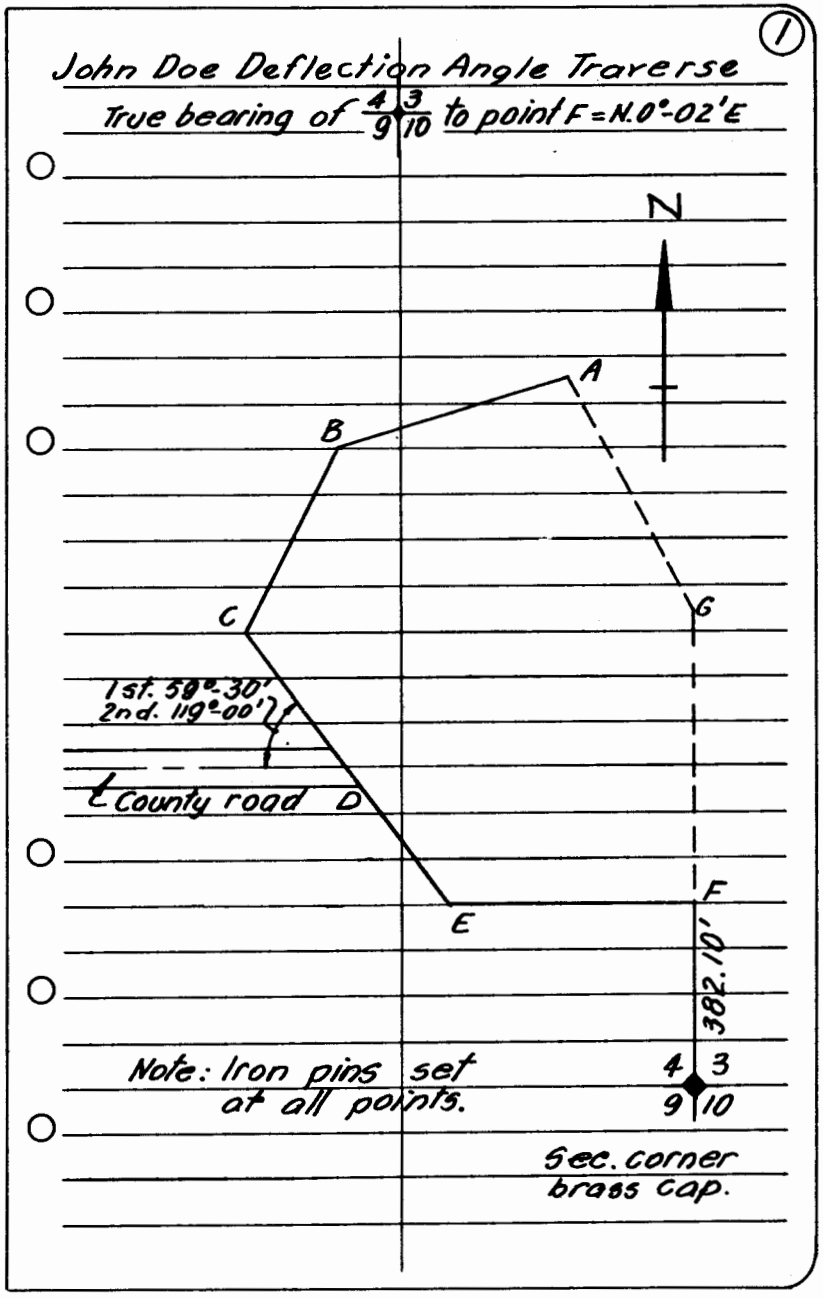
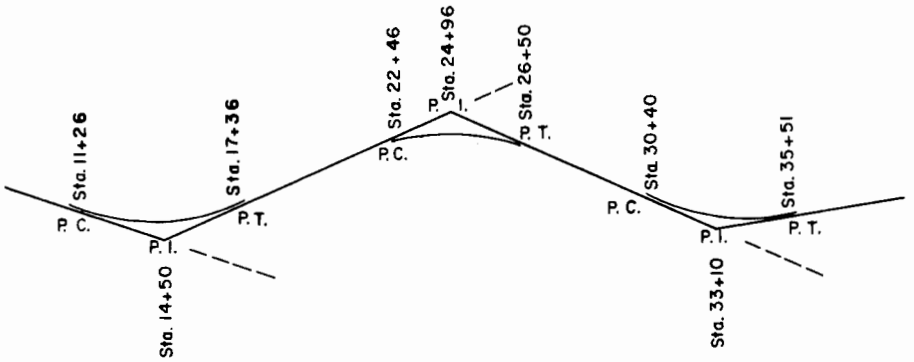


Figure 1.34-2

11. TYPES OF SURVEYS (CONT'D)

Circular Curves. It is sometimes necessary or desirable to place a circular curve at the intersection of two tangent lines. (See Figure 1.35). Curves help reduce the rate of change of direction, improve hydraulic characteristics of canals and drains, or may be put in to improve appearance of an installation. Railways and highways use circular curves, in conjunction with spirals or transition curves to give smoother, safer riding while changing direction.

CIRCULAR CURVES IN TRAVERSE SURVEY



Note: Distance from PC to PI is the tangent distance of the curve while the distance along the curve from PC to the PT is the curve distance.

Figure 1.35

In conservation work circular curves may well be applied to drains, irrigation canals and ditches, dikes and other earthen structures.

Elements of a circular curve:

a. R - radius of the curve in feet.
b. V - vertex or point of intersection (PI) of the two tangents to the curve.
c. I - intersection angle is the deflection angle (right or left) of the two tangents and is equal to the angle between the radii.
d. P.C. - point of curvature is the point where the tangent "A" (See Figure 1.36) ends and the curve begins.
e. P.T. - point of tangency is the point where the curve ends and the tangent "B" begins.
f. L - length of curve from the P.C. to the P.T. in feet.
g. T - tangent distance is the distance from the Vertex V (or P.I.) to the P.C. or P.T. in feet.
h. E - external distance is the distance from the Vertex V, to the midpoint of the curve in feet.
i. C - the long chord is the straight line distance from the P.C. to the P.T. in feet.
j. M - middle ordinate is the distance from the midpoint of the curve to the midpoint of the long chord in feet.

11. TYPES OF SURVEYS (CONT'D)

Circular Curves (cont'd)

k. D - the degree of curve is that angle at the center subtended by a chord of 100 feet.

ELEMENTS OF CIRCULAR CURVE

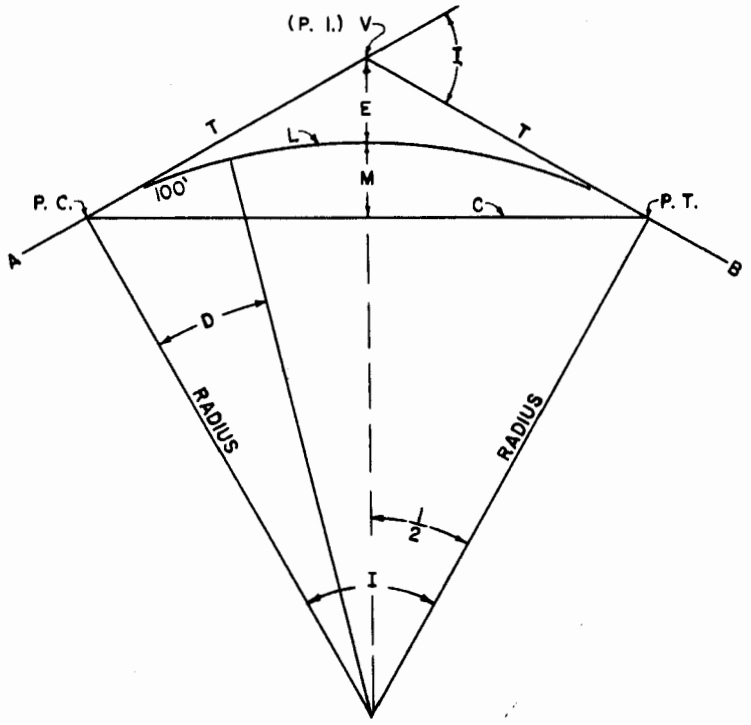


Figure 1.36

The following relationships exist between the various curve elements:

a. $T = R \tan \frac{I}{2}$

b. $E = R \operatorname{exsec} \frac{I}{2}$

c. $\sin \frac{1}{2} D = \frac{50}{R}$

d. $C = 2R \sin \frac{I}{2}$

e. $L = 100 \frac{I}{D}$ **(Curve length measured along chords)**

f. $M = R \operatorname{vers} \frac{I}{2}$

The example on the following page will illustrate the use of the foregoing formulae with the use of natural trigonometric tables only.

11. TYPES OF SURVEY (CONT'D)

Example 1

Given: Intersection angle, I = 38°40'; tangent distance T = 150.0'.

Find:
1. Radius, R
2. Degree of Curve, D
3. Length of Curve, L
4. Compute external distance, E
5. Compute deflection angles and points on the curve

(1) From "a" above, to find Radius, R:

$$T = R \tan \frac{I}{2} \quad \text{or} \quad R = \frac{T}{\tan \frac{I}{2}}$$

$I = 38°40'$, $\frac{I}{2} = 19°20'$

$\tan 19°20' = .35085$

$$R = \frac{150.0}{.35085} = 427.53 \text{ feet}$$

(2) From "c" above, to find degree of curve:

$$\sin \tfrac{1}{2}D = \frac{50}{R} = \frac{50}{427.53} = .11695$$

$\frac{1}{2}D = 6°43'$

$D = 13°26'$

(3) From "e" above, to find length of curve, L:

$$L = 100 \times \frac{38.66°}{13.43°} = 287.86 \text{ feet}$$

Note: The length of curve may also be found by the formula L = RI, where the angle I is in radians. This length will be slightly longer and more precise, as it represents the true arc length.

(4) From "b" above, $E = R \operatorname{exsec} \frac{I}{2}$:

$E = 427.53' (.05976) = 25.55'$

Parts of this same problem may be resolved by the use of prepared tables. These tables usually give the elements for a 1° curve, dividing the given figures by an element of the desired degree of curve the proper values are obtained.

The following example has the same elements given as in Example 1:

11. TYPES OF SURVEYS (CONT'D)

Circular Curves (cont'd)

(1) In a table of tangent distances for a 1° curve, where I = 38° - 40' you will find a tangent distance of 2010.2'. Dividing this by the given tangent distance of 150.0' in Example 1, we get 13° - 26' as the degree of Curve, D (a small correction was made from correction tables for tangent distances).

(2) From a table of Radii, where D = 13° 26' we find Radius R equals 427.50' (Example 1 was 427.53).

(3) Length of curve figured same as in 1.

(4) From a table of externals to a 1° curve, where I = 38°40', find an external distance of 342.4'. Divide this by D of 13°26' and obtain external distance, E, for the curve in question.

$$E = \frac{342.4}{13.42^{\circ}} = 25.50' \quad \text{(Example 1 = 25.55')}$$

Tables for solving curve problems may be found in "Railroad curves and Earthwork" by C. F. Allen.

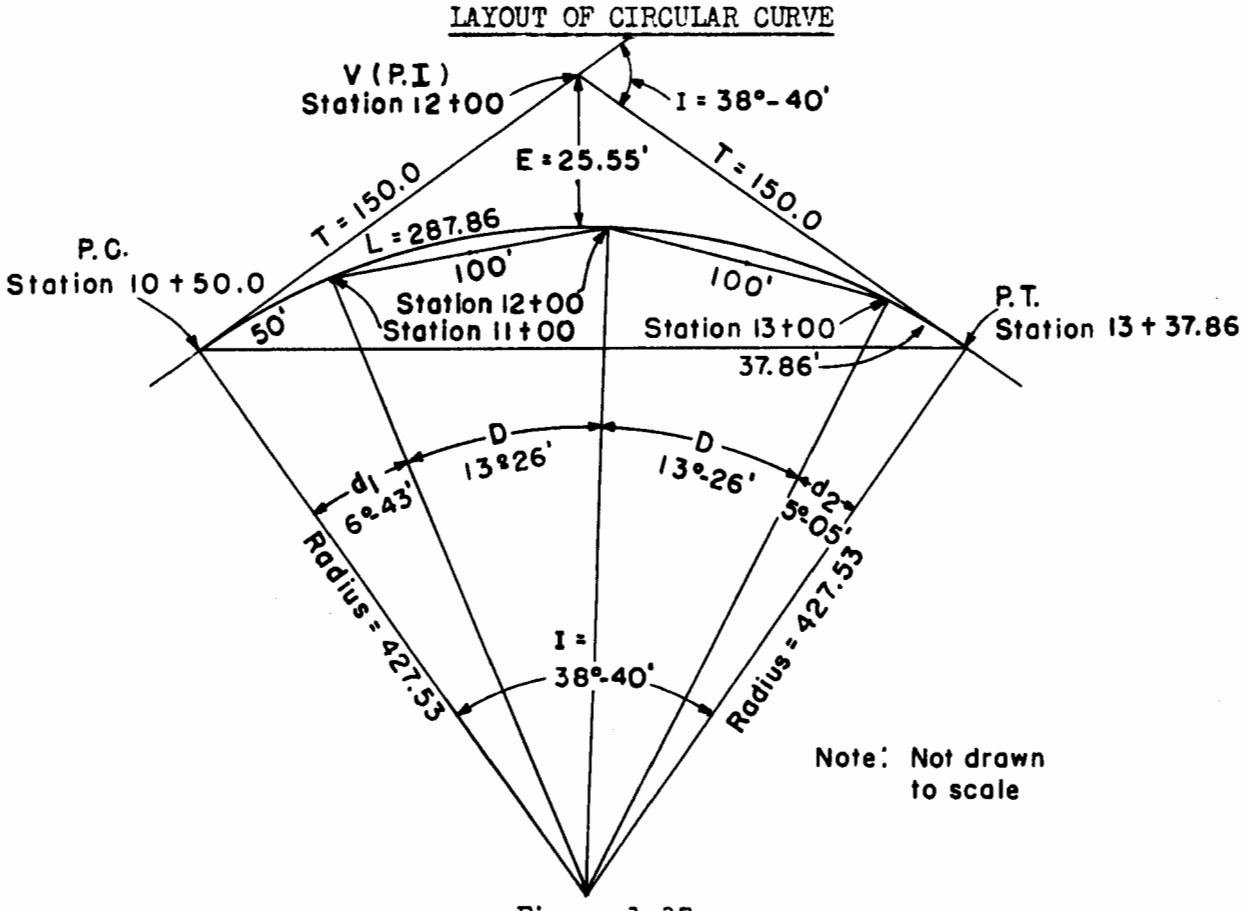


Figure 1.37

11. TYPES OF SURVEY (CONT'D)

When the elements of the curve have been calculated, the actual field work of laying in the curve may be done by (1) chord stationing method or (2) arc method. The chord stationing method will be explained here.

The first step in the field location of a curve is to mark on the ground the P.C. and P.T. locations (by measuring on line from the vertex of P.I.). The calculation of the deflection angle for a 100' chord and sub-chords (less than 100') should then be made. The deflection angle for a 100' chord is $\frac{D}{2}$, and for a sub-chord it may be found by proportion.

See Figure 1.37.

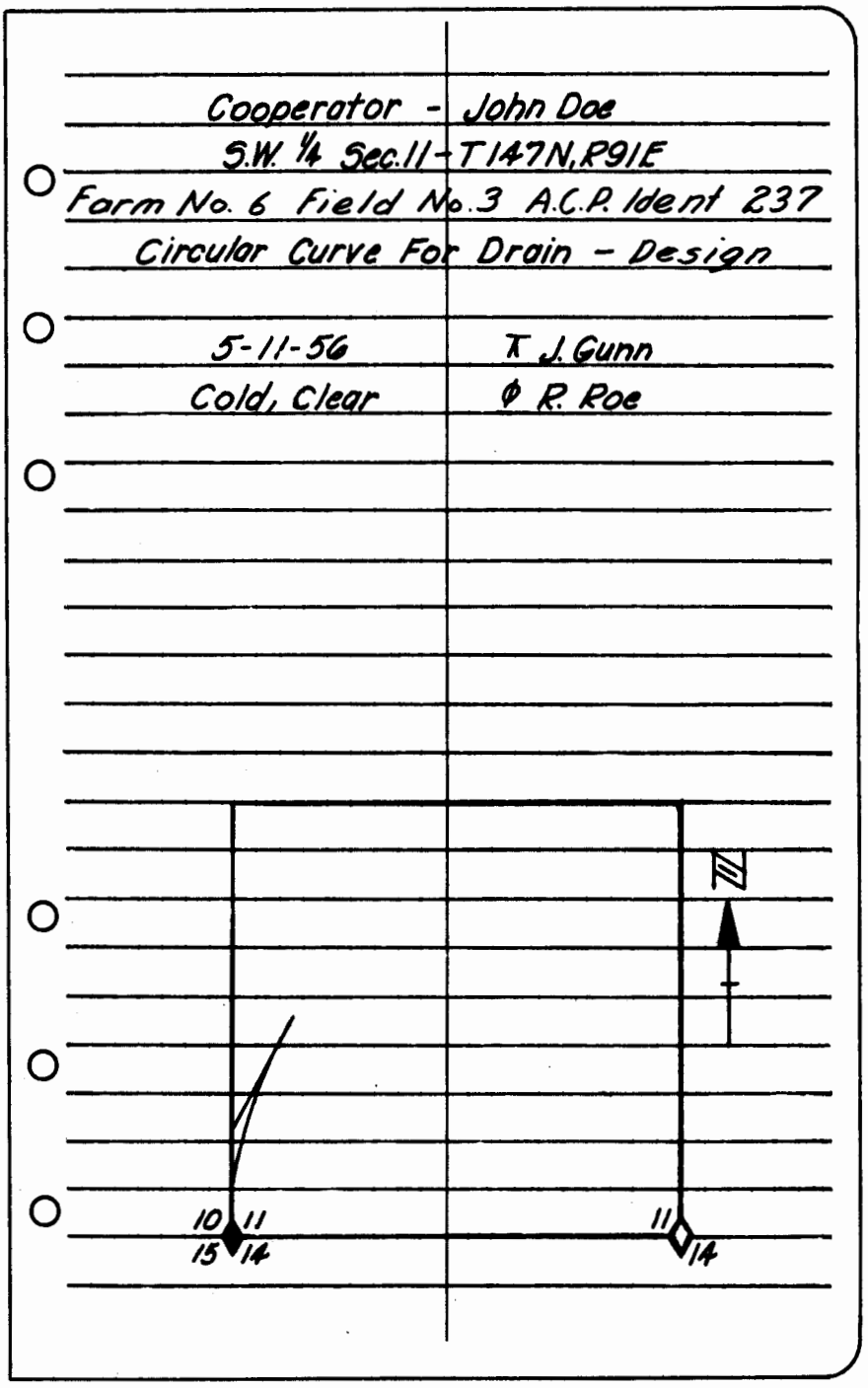
$$d_1 = \frac{50}{100} \times 13°26' = 6°43', \quad \frac{d_1}{2} = 3° - 21.5'$$

$$D = 13°26', \quad \frac{D}{2} = 6° - 43'$$

$$d_2 = \frac{37.86}{100} \times 13°26' = 5° - 05', \quad \frac{d_2}{2} = 2° - 32.5'$$

A sub-chord was used at the beginning of the curve to make the stationing come out even; i.e., 10+50+50' = 11+00. This curve could have been run in with two full chords of 100' and a sub-chord of 87.86'. With the transit set on the P.C., sight the P.I. or Vertex and set the vernier on 0-00'. Then turn a deflection angle toward the P.T. of 3° - 21.5' (see above) for the sub-chord of 50'. Measure a distance of 50' from the P.C. to the point on the curve. A flagged nail is commonly used to identify each point where the line of sight intersects the curve centerline. From the P.C. (station 10+50) the point would fall at station 11+00 on the curve. (See Figure 1.37). For the next full chord of 100' an additional 6° -43' is added to 3° -21.5' to give an accumulated deflection of 10° - 04.5' from the tangent line. A distance of 100' is measured from station 11+00 on the curve to the intersection of the line of sight and the curve centerline (station 12+00). This point is also marked. The next deflection angle is also 6°43' as the chord is 100' long. The additional 6°43' is turned giving a total deflection from the tangent line of 16° - 47.5'. A distance of 100' is measured from station 12+00 to station 13+00 on the curve, and marked. The last deflection angle for this curve is for the sub-chord of 37.86' and is 2° - 32.5' (see above) and when added to 16° - 47.5' gives a total deflection of 19° - 20'. This angle when turned from the tangent line to the P.T. while the transit is on the P.C. should be equal to $\frac{I}{2}$; i.e., $\frac{38°40'}{2} = 19°20'$ and is a check on deflection angle calculations.

Transit-Stadia Traverse (Elevations Not Required). The transit-stadia survey (sometimes called a stadia-azimuth survey) is used extensively for preliminary work requiring the locations of boundaries, position of points, objects, lines, and elevations. This method of surveying is rapid and



FIELD NOTES FOR CIRCULAR CURVE
Figure 1.38-1

Sta.	Point	Deflection Angles	Curve Description	
8				
9				
9+15.4	Section Corner			
10				
			D =	13°26'
10+50	P.C.	0°-00'	R =	427.5
			L =	287.9
11		3°-21.5'	T =	150.0
			I =	38°40'
12	P.I.	10°-04.5'		
13		16°-48.5'		
13+329	P.T.	19°-20'		
14				
15				

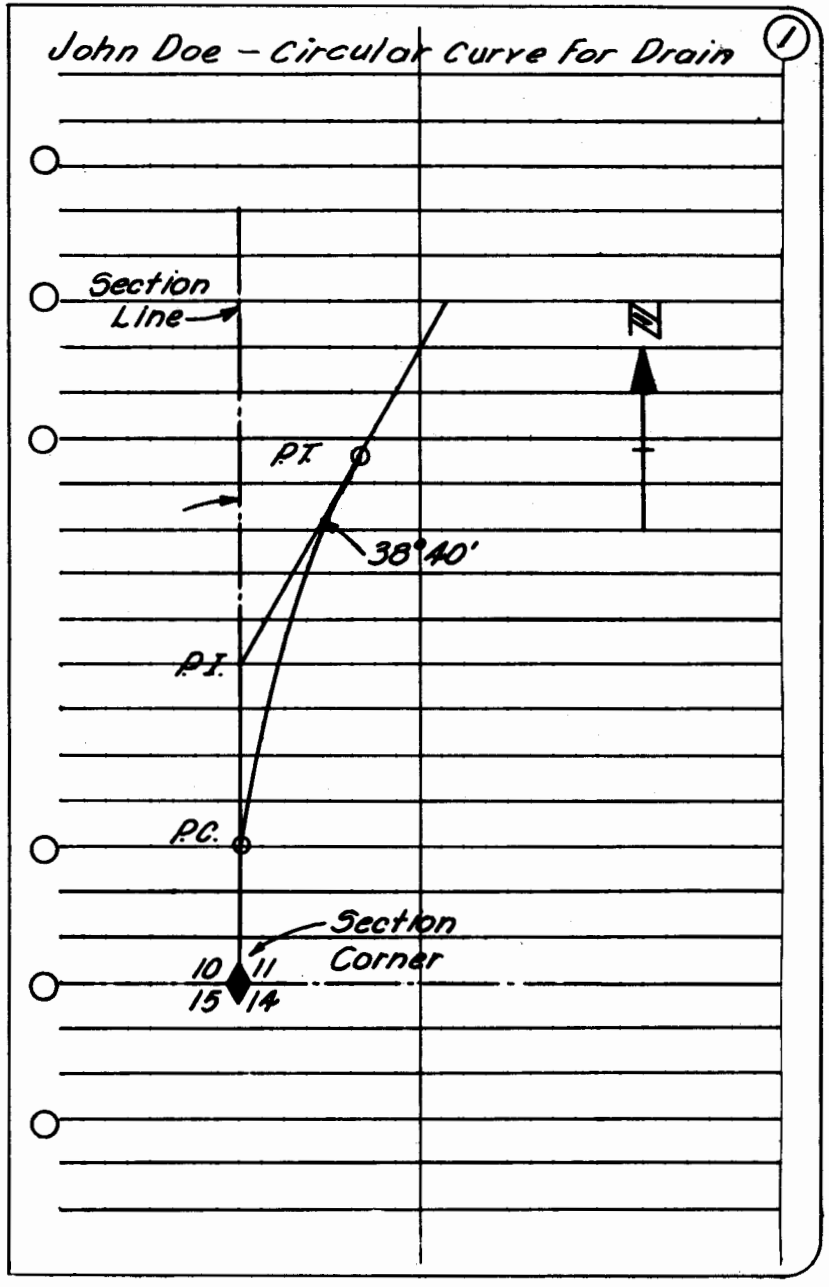


Figure 1.38 - 2

11. TYPES OF SURVEYS (CONT'D)

Transit-Stadia Traverse (cont'd) sufficiently accurate for many types of Soil Conservation work.

Stadia surveys usually consist of two parts: (1) the traverse and (2) the taking of topography. The first is the horizontal control and the second is the vertical control which provides for the taking of elevations for preparation of topographic maps, location of details or taking of side shots. The two parts of a transit-stadia survey may be done together or separately. For small areas the simultaneous establishment of the traverse and the topography is frequently done, but for large areas it is advisable to run the vertical and horizontal controls and check them before the topography is taken. This will detect errors before they are reflected in the topographic shots and on any maps being prepared.

The field work consists of determining horizontal angles (azimuths) to points or objects and obtaining distances between points by stadia. When running a traverse by the transit-stadia method all directions and angles are referred to a reference line. This line may be an established line from a previous survey, a true meridian, magnetic meridian, or an assumed meridian. The measurement of the azimuth angle is always made in a clockwise direction from the zero azimuth. On any given survey the position of zero azimuth should always be the same -- usually north. (See Figure 1.39).

AZIMUTHS FROM NORTH

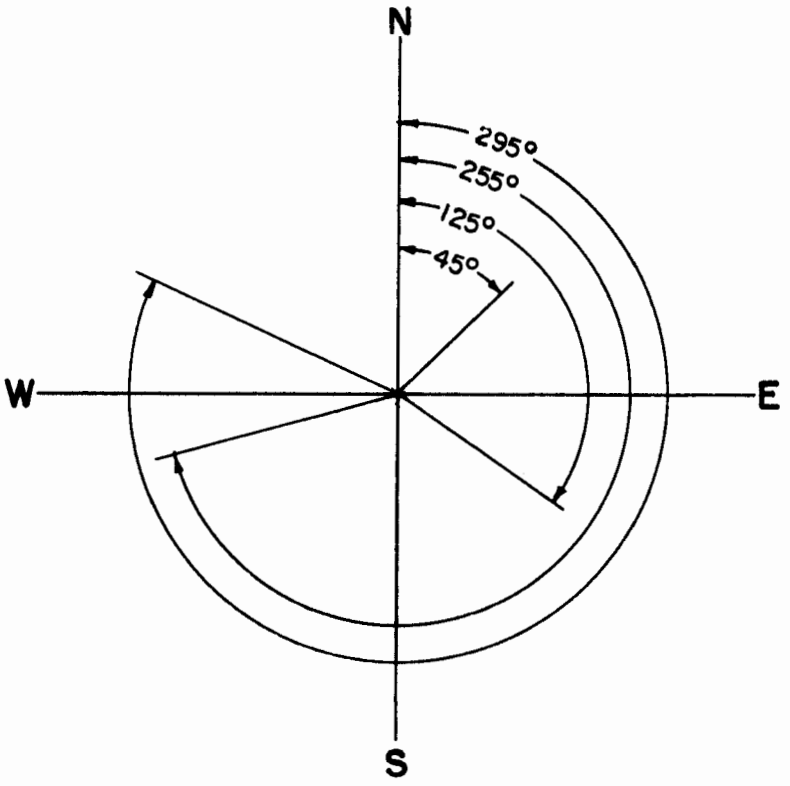


Figure 1.39

11. TYPES OF SURVEYS (CONT'D)

Transit-Stadia Traverse (cont'd)

When starting the transit-stadia survey, the instrument is oriented at the first station in this manner:

a. Set the instrument on Station A (assume azimuths will be taken from magnetic north).

(1) Set horizontal circle on 0°.
(2) Point telescope toward magnetic north and release needle. Place 0° of magnetic circle at north point and tighten lower clamp.

b. With the instrument oriented, proceed in this manner:

(1) Loosen upper clamp.
(2) Measure all angles from magnetic north
(a) Turn and read all angles in a clockwise direction.
(3) Complete all work at Station A.
(4) Sight on Station B and read azimuth of line A-B.
(5) Keep this azimuth reading set on the circle and move instrument to Station B.

In order to carry the direction of the meridian from one transit station to the next (Station A to B) one of two methods may be used. These two methods are:

a. Set instrument on Station B. (First Method).

(1) Invert the telescope and sight on A.
(2) Tighten lower clamp.
(3) Read the azimuth again as a check to see that the reading was not changed while instrument was moved from A to B.
(4) Now turn the telescope on its horizontal axis (plunged).
(5) It now points in the direction of A-B, whose azimuth we already have.
(6) The instrument is now oriented.
(7) Loosen the upper clamp and proceed in the same manner as at Station A.

b. Set instrument on Station B (Second Method).

(1) Determine azimuth of line B to A by;

a. Subtracting 180° from the azimuth reading of line A-B if the azimuth is greater than 180° , or
b. Adding 180° to the azimuth reading of line A-B if the azimuth is less than 180° .

(2) Set the circle on the azimuth reading of line B-A.
(a) Sight to A with telescope direct.

Transit-Stadia Traverse (cont'd)

(2)
(b) Instrument is now oriented at B.
(c) Proceed with survey as before.

This method avoids the danger of the circle setting becoming shifted as the instrument is carried from Station A to B. It also eliminates any error resulting from the line of sight not being perpendicular to the horizontal axis. (In method "b" the telescope is not plunged). There is a possibility, however, of computing the back azimuth BA incorrectly.

Distances between transit stations are read twice; that is, a reading is taken from A to B and from B to A (See Figure 1.40). At each setup of the instrument a distance reading will be made both back and forward. This will give two independent stadia observations between transit stations and the average of the two readings will be the most probable value and also serve as a check.

Whenever possible, stadia readings should be taken with the telescope approximately level, thereby eliminating the necessity for reading vertical angles.

Figure 1.40 shows a method of note keeping where the azimuths, magnetic bearings, rod interval, vertical angles, and horizontal distances are shown. The rod interval is shown to facilitate checking the horizontal distances.

FIELD NOTES - STADIA TRAVERSE SURVEY HORIZONTAL CONTROL

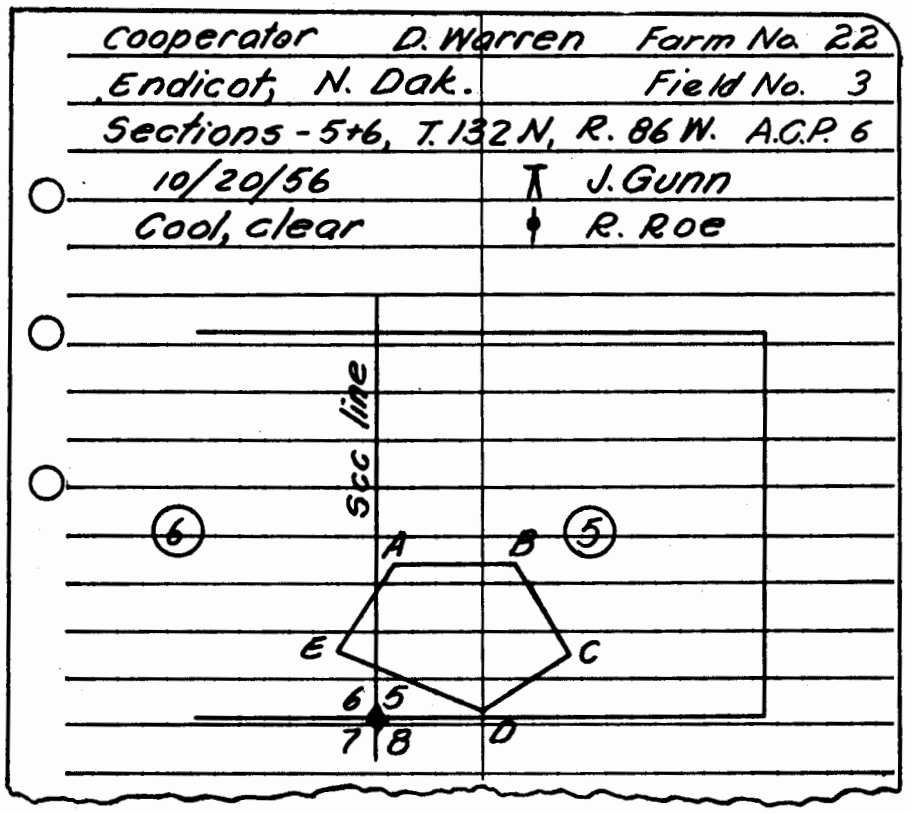


Figure 1.40 - 1

(1)

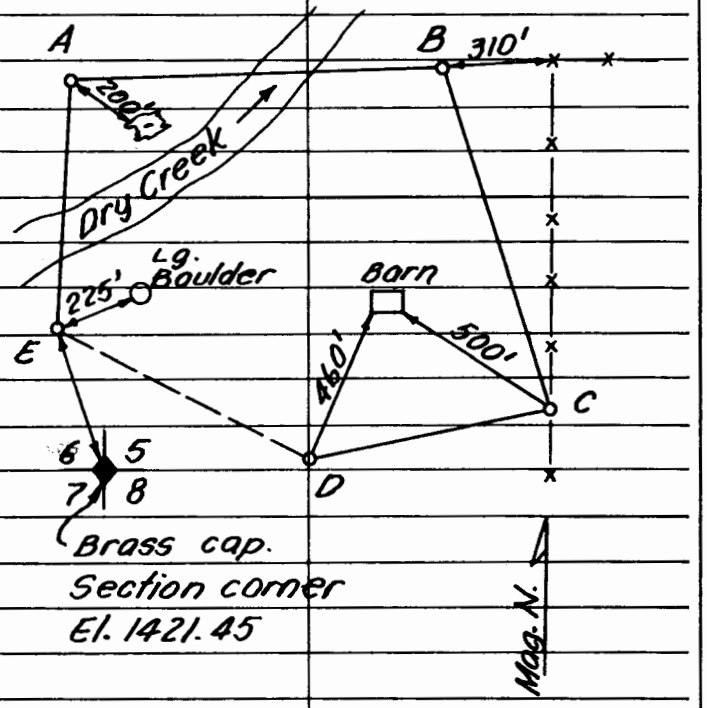
Sta.	Obj.	AZ.	Mag. B.	Rod interval	Ver. Ang.	Hor. Dist.
A	B	88°-00'	N88°E	11.20		1115
	E	181°-30'	S1°-30'W	7.26		
B	A	268°-30'	S88°-30'W	11.10		
	C	160°-05'	S 20°E	13.42	+3°-10'	1336
C	B	340°-07'	N 20°W	13.40	-3°-10'	
	D	251°-15'	S 71°W	6.37		636
D	C	75°-14'	N 75°E	6.35		
	E	309°-11'	N51°W	7.17	-4°-50'	711
E	D	129°-00'	S 51°E	7.15	+4°-50'	
	A	1°-29'	N1°-30'E	7.30		
615/718		175°-13'	S4°-47'	4.10		410

Note: Sample notes. No attempt was made to see if traverse closed.

D. Warren Stadia Traverse Field 6 (1)

f+c=1.0 not included in recorded distances.

T at A oriented 0° on Mag. N.



FIELD NOTES - STADIA TRAVERSE SURVEY - HORIZONTAL CONTROL
Figure 1.40-2

11. TYPES OF SURVEYS (CONT'D)

Transit-Stadia Traverse (cont'd)

Vertical angles under 2° may be neglected when using stadia to obtain distances on preliminary surveys. The stadia distances (shown in Figure 1.40) which had vertical angles associated with them were corrected by the use of tables.

Stadia surveys should be tied into existing surveys, legal corners, etc. whenever possible as this facilitates plotting and orienting the survey. It cannot be over emphasized that clear, complete sketches in the field notebook are necessary for the correct interpretation of the notes.

Transit-Stadia Traverse (Elevations Required). In making this type of survey the elevations of points, as well as their locations in a horizontal plane, are determined. This may be done after the original traverse for horizontal control has been established or may be carried on simultaneously with the establishment of the transit stations.

When a traverse has been completed and checked and it is then desired to obtain elevations of the transit points and other details, the following procedure may be used (using same survey as Figure 1.40).

a. The instrument is set on E

(1) An angle of 175° - 13' is set on horizontal circle and instrument sighted on $\frac{6/5}{7/8}$ (175° - 13' is azimuth of E to $\frac{6/5}{7/8}$ see Figure 1.40).
(2) Instrument is now oriented.
(3) Proceed with establishing elevations as follows:
(a) Find elevation of point E and H.I. by taking rod reading (4.63) on bench mark $\frac{6/5}{7/8}$, (elevation 1421.45),
measure instrument height with tape (4.37) then
1421.45 + 4.63 - 4.37 = elevation of point E = 1421.71.

Note: A bench mark with an assumed elevation may be used if sea level datum is not required.

(b) Turn azimuths, take stadia readings and elevations of points accessible to Point A.

When it is necessary to take vertical angles for the determination of elevations, proceed as follows:

a. Tie a narrow band of red cloth around rod to mark H.I. (4.37').
b. Sight the middle horizontal cross hair at a point on the rod equal to the H.I.

(1) This will give the vertical angle between the ground at the instrument and the ground at the foot of the rod.

11. TYPES OF SURVEYS (CONT'D)

Transit-Stadia Traverse (cont'd)

b. (2) Clamp the vertical circle and read the angle.

For convenience, the location of points can be readily done by taking readings in the following order:

a. Set the vertical hair on the rod and clamp the upper plate.
b. Read the distance by setting one stadia hair on a whole foot, and noting the position of the other stadia hair on the rod.
c. Set the middle horizontal hair on the point (H.I.) on the rod to which the vertical angle is to be taken.
d. The transitman then signals the rodman to the next point and records the data.

The set of notes, Figure 1.41, illustrates the taking of details from a traverse which had been run previously.

The reduction of the notes in Figure 1.41 was done by the use of stadia reduction tables. It may sometimes be more practical and faster to make the horizontal and vertical corrections in the field with the use of a stadia slide rule.

Differences in elevation in Figure 1.41 were computed as follows:

a. From stadia reduction tables, found in text on surveying, the positive vertical angle (+0° - 31') for point 6 corresponded to a value of 0.90'. This multiplied by the distance in hundreds of feet 4.45 x 0.90 = +4.0'.

Horizontal Correction = 0.04' therefore distance was left at 445'
Difference in elevation = 4.45 x 0.90 = +400 feet.
Elevation = 918.30 + 4.00 = 922.30 feet

The sign of the vertical angle determines whether the difference of elevation should be subtracted or added to elevation of point E.

Topographic Surveys. Topographic surveys are made of areas or sites to determine the relief of the ground and to establish the location within the area of both natural and man-made features.

The types of surveys which will be considered are:
a. Grid survey
b. Plane table survey

Grid Survey. The grid survey provides a systematic method of taking topography, location of borings, providing elevation points for land leveling or, in general, a method for establishing at regular intervals of distance, locations, and elevations of points.

11. TYPES OF SURVEYS (CONT'D)

Grid Survey (cont'd)

Grid systems for taking topography do not necessarily require a stake to be set at each grid point. However, for land leveling, stakes or lath are set at the determined grid interval (say 100') and are left until the earthwork is completed and checked.

FIELD NOTES - STADIA TRAVERSE SURVEY - HORIZONTAL AND VERTICAL CONTROL

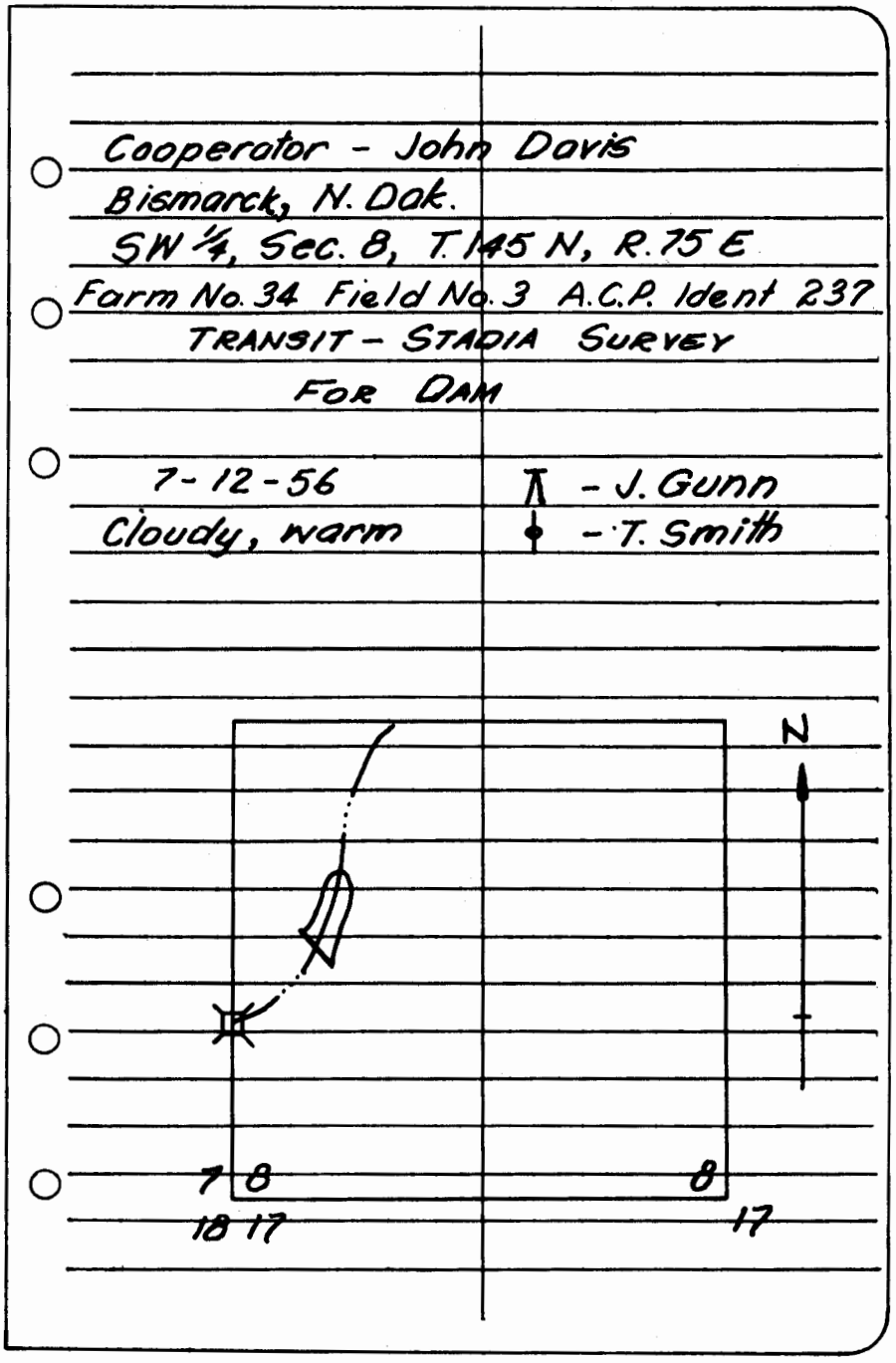


Figure 1.41 - 1

Sta.	Stadia Dist.	Azimuth Angle	Vert. Angle	B.S. +	H.I.	F.S. Diff. − Elev.	①
Instrument at A							
B.M.				1.05	927.30		
⊡ A		0°south				4.8	
1	388	323°-30'	0°-00'			5.6	
2	307	269°-45'	0°-00'			4.8	
3	453	269°-50'	-0°-31'			4.8 -4.1	
4	386	240°-00'	0°-00'			4.7	
⊡ B	752	223°-40'	0°-00'			9.0	
Instrument at B							
⊡ B				4.6	922.90		
⊡ A	752	43°-40'	0°-00'			0.40	
5	82	24°-50'	0°-00'			50	
6	445	161°-10'	+0°-31'			4.6 +4.0	
7	290	275°-40'	+0°-52'			4.6 +4.4	
⊡ C	722	333°-15'	+0°-54'			4.6 +11.35	
Instrument at C							
⊡ C				4.5	934.15		
⊡ B	722	153°-15'	-0°-54'			4.5 -11.35	
8	228	92°-25'	-1°-44'			9.0 -6.9	
9	190	45°-40'	-1°-56'			5.5 -6.4	
10	157	22°-20'	-2°-10'			6.1 -5.9	
⊡ A	850	96°-48'	-0°-29'			4.5 -7.1	

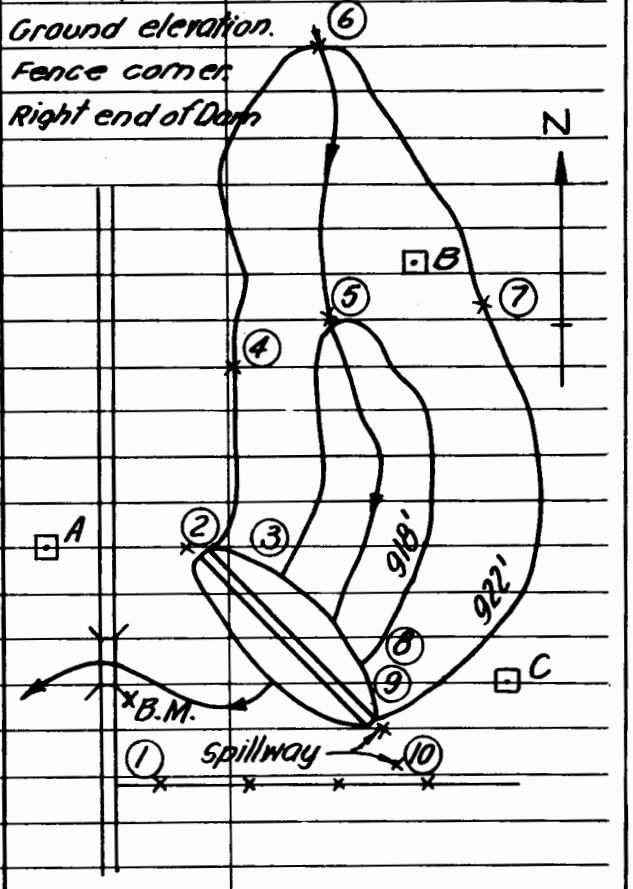
John Davis Transit Survey For Dam ①

Elev.

π Gunn

φ Smith

Elev.	
926.25	Top of painted bolthead-S.E. Cor. Bridge
922.5	Ground elevation.
921.7	Fence corner
922.5	Right end of Dam
918.4	
922.6	
918.30	
918.30	
922.50	
917.9	
922.3	
922.7	
929.65	
929.65	
918.30	
918.2	
922.2	
922.1	Left end of Dam
922.5	Sta. 0+00 spillway



FIELD NOTES - STADIA TRAVERSE SURVEY - HORIZONTAL AND VERTICAL CONTROL

Figure 1.41-2

11. TYPES OF SURVEYS (CONT'D)

Setting Stakes (100' grid -- See Figure 1.42)

a. Set transit over A-0 and lay out a base line along south side of field. (A right angle prism may be used instead of the transit)

(1) When a three-man crew is available, the two rodmen chain in lath at each 100' point on line and the transitman checks each lath carefully for line.

When a two man crew is being used, one man puts in lath approximately 300 to 400 feet on line (from A-0 to A-12). When the sighting lath are established, he returns to Station A-0 and the instrument man and the rodman, beginning at A-0, chain and set a lath at 100 foot intervals. The lath are set with the flat side toward the field or in the direction of irrigation when grid is used for land leveling.

GRID SURVEY RECTANGULAR FIELD

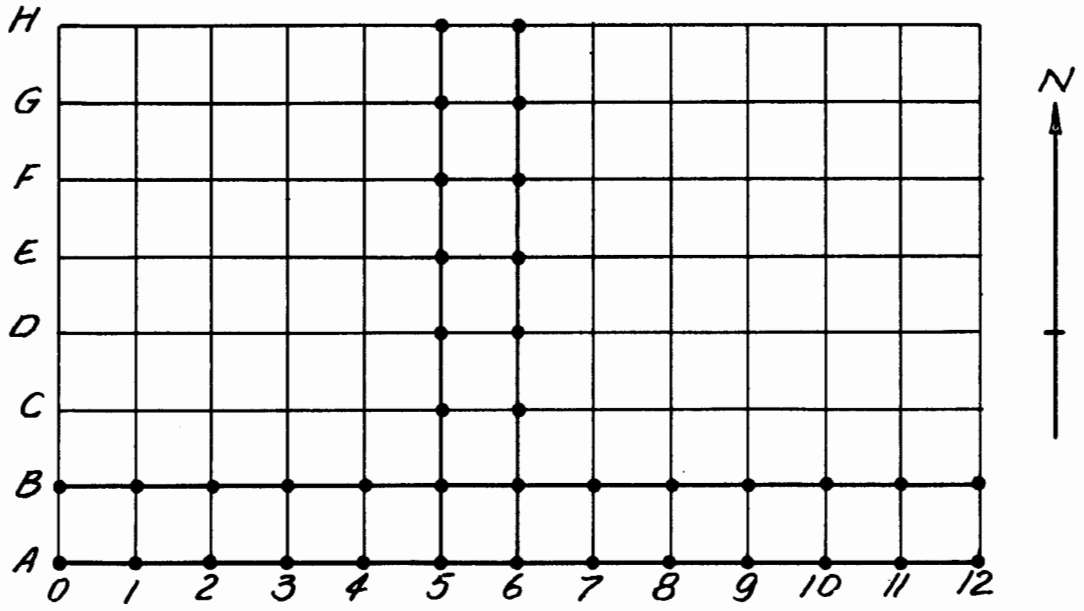


Figure 1.42

11. TYPES OF SURVEYS (CONT'D)

Setting Stakes (cont'd)

b. Move transit to B-0 and backsight on A-0. Turn 90° angle and set line B in same manner as line A.

c. Lines 5 and 6 are set by moving transit to points A-5 and A-6, turning 90° angles off of line A and setting lath as previously described.

Note: Chained distances and 90° angles should be as exact as possible when running base lines to insure that the grid stakes will form squares and not be diamond shaped.

d. The rest of the stakes may be set by (1) continuation of the above procedure; (2) may be put in by eye (see below); (3) may be put in by using the tape to measure one way and sighting by eye in the other, or (4) by using either a double or single right angle prism. Because prisms are compact and easy to carry and are instantly ready for work, they are a valuable aid for the engineer or surveyor, wherever right angles are to be established.

Where the field is irregular in shape and a minimum of gridding is imperative, the following procedure is offered. (See Fig. 1.43)

(1) Determine the maximum distance across the area in the direction of intended gridding. (This may be done by inspection on most areas). (See lines 3 and 4 in Figure 1.43)
(2) Run base lines (3 and 4) as previously described.
(3) Run in base lines perpendicular to lines 3 and 4 at longest portion of field (lines G and H). This may be done by setting instrument on G-3 and turning a 90° angle off line 3 and setting stakes on line G as before described. The instrument is then set on H-3 and line H is staked.
(4) The rest of the area may be staked by sighting 3 ways; that is, to set stake F-2, sight by eye diagonally over stakes G-3 and H-4, east through F-3 and F-4, and north through G-2 and H-2. The intersection of these three lines will give the position of F-2. (See Figure 1.43). With little practice large areas may be gridded without further use of the transit. This method can be used for ordinary land leveling grids where the areas are independent of master grid systems, project grids, etc. For work requiring great precision, the use of the transit and tape is definitely recommended for setting each point.

Plus Stakes. It is sometimes necessary to set stakes between full grid stations to more accurately show the conditions as they exist in the field. Where a high or low local area falls between grid stations, a "plus" stake or lath is set in. This is very important in land leveling to more accurately determine yardage.

GRID SURVEY - IRREGULAR FIELD

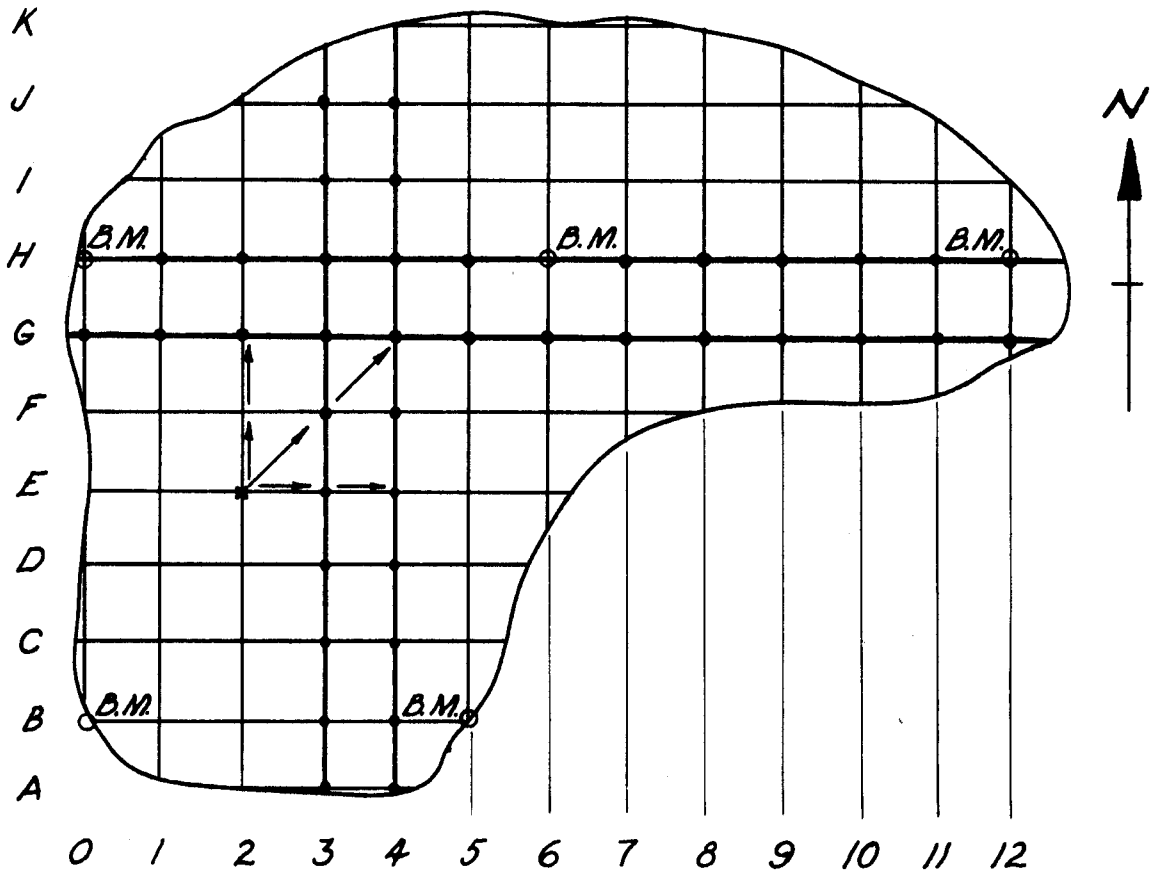


Figure 1.43

11. TYPES OF SURVEYS (CONT'D)

Plus Stakes (cont'd)

The system for marking or identifying these stakes is (see Figure 1.44)

a. Stake is set at point P.
b. Distance is taped at right angles from line 5 to point and added thus 5 + 71.
c. Distance is taped at right angles from line C to point and added thus, C + 80.
d. Stake is marked with these coordinates: (C + 80) (5 + 71).

Right angles from lines may be done by sighting by eye for most surveys.

PLUS STAKES IN GRID SURVEY

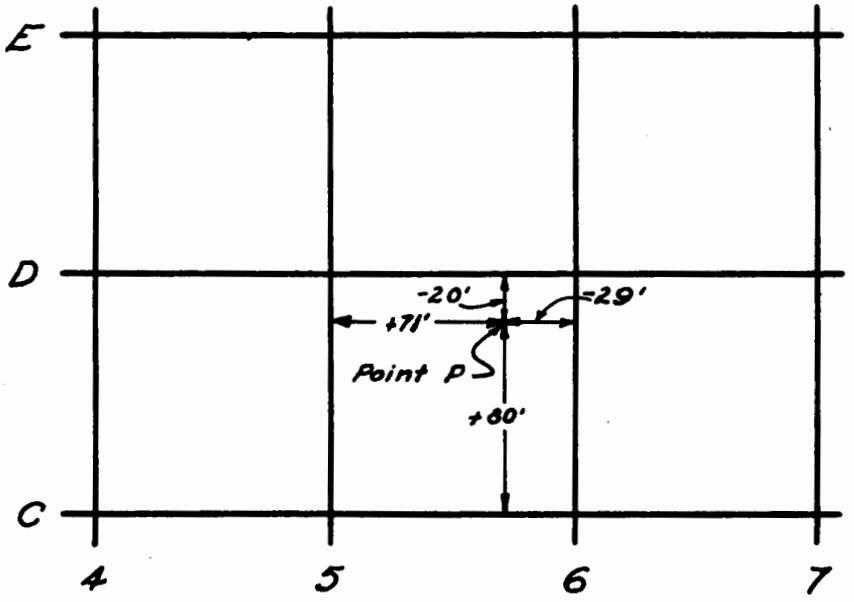


Figure 1.44

If taping is done from the D line and 6 line this procedure will be followed:

a. Distance is taped at right angles from line D to point P -- 20 feet. In going backwards from the D line toward the C line the 20 feet must be subtracted from 100 feet to establish the true relationship of the point with the grid system; i.e., (100' - 20' = 80') therefore, the point is 80 feet from the C line in a positive direction or in a direction of increasing grid notation. (A,B,C - 4,5,6, etc.)
b. The same procedure is followed in measuring to point P from the 6 line. Twenty-nine feet is measured back at right angles from the 6 line and subtracted from 100'. (100' - 29' = 71'). The

11. TYPES OF SURVEYS (CONT'D)

Plus Stakes (cont'd)

b.(cont'd) point P is 71 feet from the 5 line and the plus stake would bear the full coordinates of (C+80) (5+71).

Note: In establishing coordinates of plus stakes, care must be exercised to avoid errors due to the addition or subtraction of the "plus" distances.

Bench Levels. After the grid stakes have been set, a closed level circuit should be established. Benches should be about 600' apart over the entire area and flagged or otherwise marked for positive and ready identification (See Figure 1.27). The importance of establishing a closed level circuit of benches which are not over 600' apart cannot be imagined by the inexperienced. The bench marks should be described fully and accurately in the notes. Rod readings on B.M.'s should be read to .01'.

Taking Elevations at Grid Points. Gridding is usually begun at one end of the field if the area is too large for one setup. This simplifies notekeeping and plotting of the field data.

Using Figure 1.42 the following procedure may be used to take elevation at each grid stake.

a. Set level at about H-8 and take rod reading on B.M. at H-12 to establish the H.I.
b. Take rod readings at all stakes up to the 4 line in a consistant manner (taking the 12 line, 11 line, 10 line, etc., until the 5 line is shot).
c. Then take rod reading on B.M. at H-6 for check. (The elevation of B.M. at H-6 in the level circuit should agree with elevation just determined). An error of .05' or less is permissible.
d. Move instrument to about F-2 and take rod reading on B.M. at H-0 and establish new H.I.
e. Take elevation of remaining stakes, beginning with line 4.
f. Check into B.M. at B-0, H-6, or B-5 and check against the original B.M. elevation.

If the field is large, several setups will be necessary before shooting is completed. Keeping the sight distance 800' or less, while taking rod readings at the grid stakes, will help minimize errors due to instrument not being in complete adjustment. Rod readings on bench marks should be kept to less than 400'.

Land Leveling Grids. Grids to be used for land leveling should ordinarily be put in just prior to the actual construction. The coordinates and cuts and fills should be marked on the stakes with keel or lumber crayon. Bench mark locations should be flagged to help prevent disturbance by machinery.

11. TYPES OF SURVEYS (CONT'D)

Land Leveling Grids (cont'd)

The base lines of grid systems should be tied in and referenced to provide a means of relocating points and future extension of the grid system. Notes may be kept in the form shown in Figure 1.45.

Plane Table Survey. (See also Section, Plane table and Telescopic Alidade) When topography is taken by use of the plane table several methods can be used: (1) running an intermediate traverse from a traverse station or by closing on the starting traverse station, (2) by orienting the instrument by the 3 point method, (3) by using a combination of the two methods. The intermediate traverse is run and the topography taken concurrently and the closure is graphical. It is essential that all intermediate traverses run for the purpose of taking detailed topography be closed to prove the accuracy of the survey. The location and elevation of all points mapped are determined by using the telescopic alidade for determining direction, distance and elevations. The use of the Beaman Stadia Arc (see below) will facilitate mapping where vertical angles are read. The alidade may be used in conjunction with a transit or level. The alidade is used for obtaining distance and direction when used in conjunction with the level, and when used with the transit only direction is obtained. Inaccessible shots which do not require elevations may be located by resection or intersection.

The topography can be taken by the random shot method or by using a grid system. The random shot method is best suited for undulating, steep topography and required the use of experienced rodman. In this method the rodman has the major responsibility for determining the location of the shots to show the true topography. The grid system is used universally on flat, open land. Good results can be obtained with inexperienced rodmen, although they should know when to take shots between grid points to establish true topographic features. The shots are taken at regular intervals, usually 100 feet, the distance being determined by pacing and the direction by eye.

Beaman Stadia Arc. To speed field work on sloping land where vertical angles are read, the Beaman Stadia Arc is a valuable time saver. In cases where the instrument man is skilled in its use, a third rodman may be added.

Since the details of using the Beaman Stadia Arc may be unfamiliar to some field men, a discussion in its use is included herein. The Beaman Stadia Arc is an attachment to the vertical arc of a transit or to the plane table alidade. Its purpose is the simplification of the reduction of inclined stadia observations to horizontal distances and elevations. The Beaman Stadia Arc is based on the principle that the difference in elevation between the height of the instrument and the point where the middle cross hair strikes the rod is a multiple of the rod interval between stadia hairs. Since these differences in elevations are normally expressed by vertical angles between the points, we know that it would be necessary to have the vertical angle between the points expressed so that the function of $\frac{1}{2} \sin \underline{a}$ ($\underline{a}$ is the vertical angle) is a multiple of the rod interval.

11. TYPES OF SURVEYS (CONT'D)

Beaman Stadia Arc (cont'd)

In the formula: Difference in elevation = $\frac{f}{i}$ x Rod Interval x $\frac{1}{2}$ sin $\underline{2a}$.

Where f = focal length of objective; i.e. the distance from the optical center to the cross hairs when the telescope is focused on a distant object, i = the distance between the top and bottom cross hair of the instrument. The relationship between these two distances is expressed as the ratio $\frac{f}{i}$ in the above formula and is a constant for any given instrument which the cross hairs are fixed. This ratio $\frac{f}{i}$ is known as the stadia constant and is 100 for most instruments.

Using the above formula and selecting those vertical angles whose function of $\frac{1}{2}$ sin $\underline{2a}$ is equal to .01, .02, .03, etc. up to .90 and with $\frac{f}{i}$ = 100 the computed angles will represent the factors 1, 2, 3, etc. up to 90. These factors are represented on the V-scale of the Beaman arc. Thus, the difference in elevation between the instrument height and the ground at the rod is equal to the rod interval times the V-scale reading on the arc, plus or minus, the rod reading. The 50 on the V-scale represents a 0° reading with plus vertical angles numbered from 50 up, and minus vertical angles numbered from 50 down. Therefore, whatever the reading is always subtract 50 from it and use the algebraic remainder.

The Beaman Arc is also used in obtaining the correct horizontal distance between the instrument and the point at which the rod is held without time consuming calculations.

Looking at the formula,

Horizontal Distance = $\frac{f}{i}$ x Rod Interval x $\cos^2 \underline{a}$

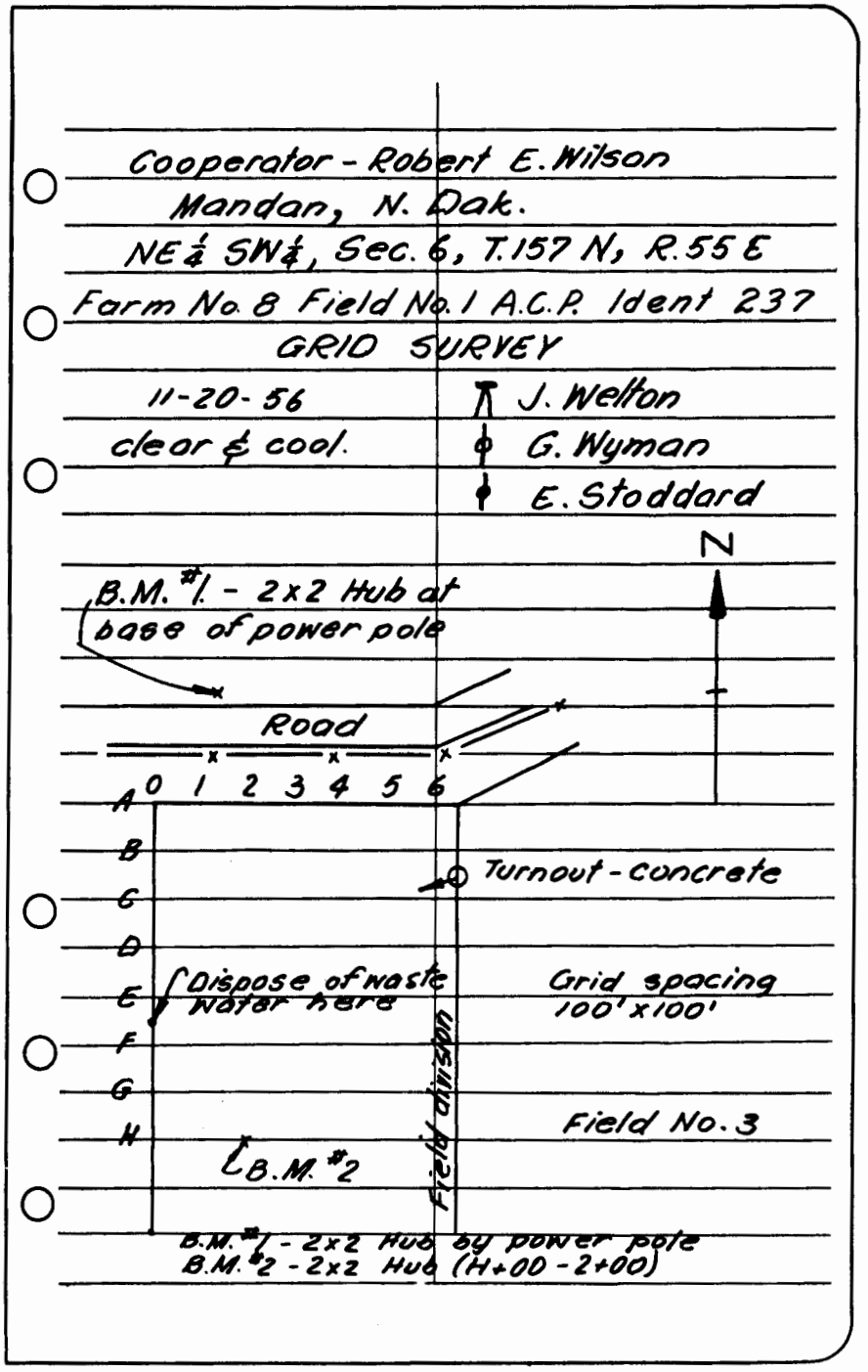
Making $\cos^2 \underline{a}$ = .99, .98, .97, etc., down to .80 with the corresponding angular values we have,

Horizontal Distance = 100 x Rod Interval x .99 etc., down to 80.

These computed angles are laid off on the H scale of the arc from the same zero, and numbered consecutively 1 (100-99), 2 (100-98), 3 (100-97), etc., up to 20. The H scale reading is then used as the percentage correction to be subtracted from the rod reading to get the horizontal distance.

Example on using the Beaman Stadia Arc:

With the instrument set up and leveled, sight on the rod and read the space intercepted by the upper and lower cross hair (Rod Interval). Let this be 6.40 feet. On the V-scale of the arc assume the index reads between 32 and 33. With the tangent screw bring the nearest whole number on the scale even with the index. This can be 33. Read the elevation on the rod cut by the middle cross hair. Let this be 7.30 feet.



FIELD NOTES FOR GRID SURVEY
Figure 1.45-1

Sta.	B.S.	H.I.	F.S	Elev.	
B.M.#1	3.74	103.74		100.00	(Assumed)
B+30 6+22			3.51	100.23	
A-6			5.8	97.9	
-5			6.1	97.6	
-4			6.5	97.2	
-3			6.9	96.8	
-2			7.2	96.5	
-1			6.8	96.9	
-0			7.1	96.6	
B-0			7.0	96.7	
-1			6.7	97.0	
-2			6.5	97.2	
-3			6.3	97.4	
-4			6.1	97.6	
-5			6.0	97.7	
-6			5.7	98.0	
C-6			5.7	98.0	
-5			6.8	97.9	
-4			6.0	97.7	
-3			6.2	97.5	
-2			6.5	97.2	
-1			6.6	97.1	
-0			6.8	96.9	
B.M.#2			4.06	99.68	

Robert E. Wilson Grid Survey Field No. 1

2x2 Hub by power pole - 40'N. of road ℄

Invert Elev. 15" conc. turnout (NW.S. 101.54)

2"x2" Hub (H+00 - 2+00) Elev. 99.67

Figure 1.45-2

11. TYPES OF SURVEYS (CONT'D)

Beaman Stadia Arc, (cont'd)

With the rod interval reading 6.40 we know it represents a distance of 640 feet. The V-scales read 33 and the rod reading is 7.30. The desired multiple then is 33-50 =-17, and the vertical difference equals -17x6.40= -108.8. The difference in elevation between the instrument and the base of the rod is then -7.30-108.8 = -116.1 feet. The minus sign indicates that the point at the rod is lower than the instrument.

The true horizontal distance is found by means of the H-scale which gives at the same pointing a direct reading of the percentage correction (always subtracted) necessary to reduce the observed stadia distance reading to the true horizontal distance. Thus in the above example you will note that on the H scale the index coincides with 3, or 3 x 6.40 = 19.2 ft. and 640 feet - 19.2 feet = 620.8 feet, being the true horizontal distance. The (f+c) of the instrument should be added to this true horizontal distance. The (f+c) is a stadia constant and represents the distance from the plumb line center of the instrument to the point of outer focus. For practical purposes this is one, so that 1 foot can be added to the above calculated true horizontal distance.

An explanation of the notes in making a traverse survey with topography using the Beaman Arc and plane table is given below.

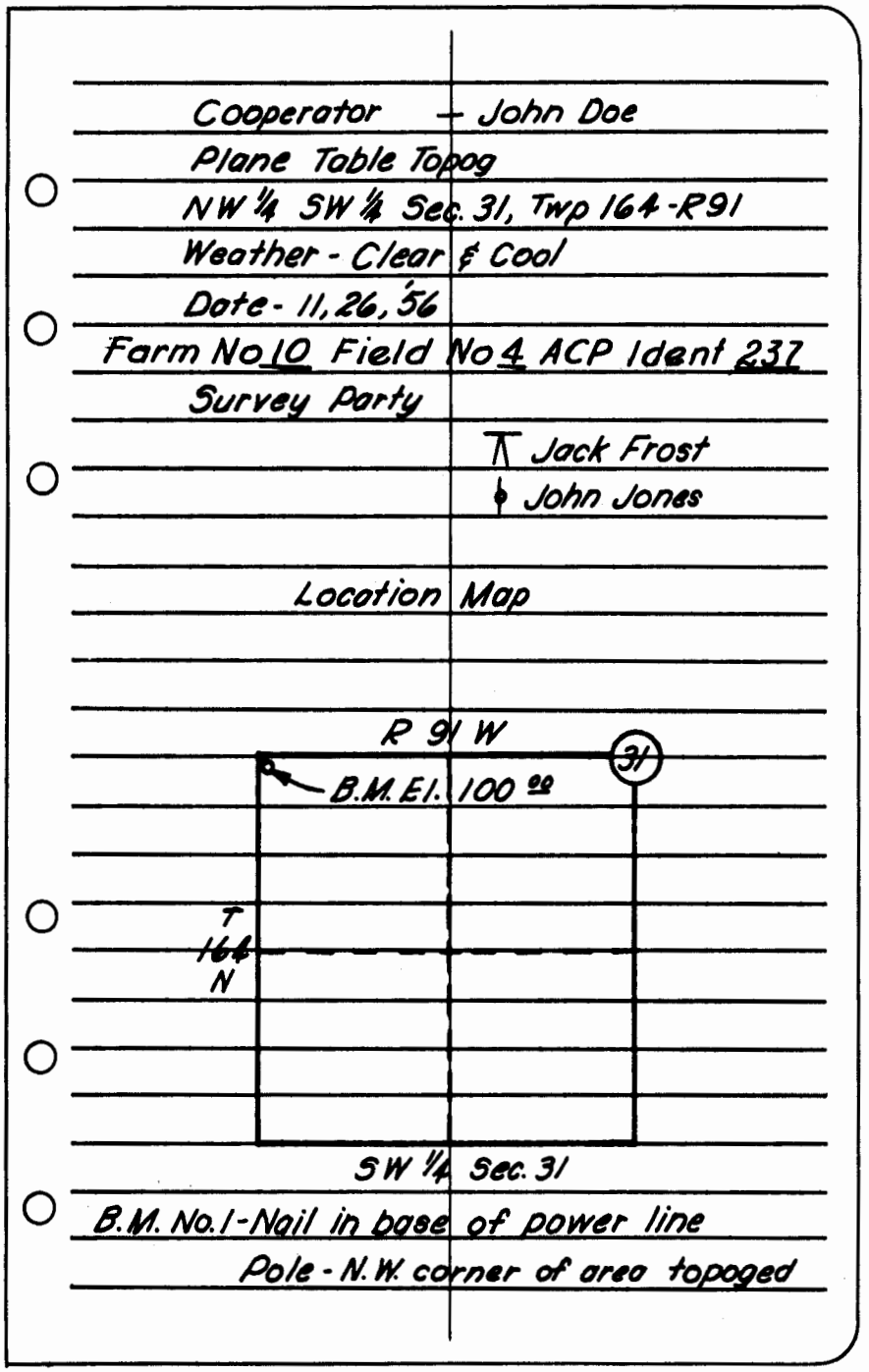
The front sheet and subsequent sheets can be set up as shown in the accompanying illustration. An explanation of the origin and use of the figures in each column of the notes follows.

1st Column - Distance. The stadia distance is obtained by reading the length of the rod showing between the top and bottom cross hairs of the instrument. For example, the first distance shown on the illustration (635 feet) is measured by 6.35 feet of rod showing between the top and bottom cross hairs. Normally a horizontal correction per hundred feet would be made by reading directly on the inner row of graduations marked horizontal. In this case no correction was made since the total correction would have been less than one foot. Whether the correction should or should not be made is determined by the accuracy required.

2nd Column - Arc. This is the actual reading of the Beaman Arc. The Beaman arc reads 50 when the telescope is level. A reading larger than 50 shows the telescope is tilted up while a reading of less than 50 shows that the telescope is tilted down hill.

3rd Column - Product. To obtain the numerical value of the product the distance will be multiplied by a number which is the numberical difference between the Arc reading and 50. For example, with a distance of 635 feet and an Arc reading 52, the product would be 635 x 2 = 1270. Since the instrument is calibrated 1:100 the product becomes 12.7. To obtain the proper sign of the product the following conditions will govern.

1. On Back Sights.
   a. Arc more than 50 - Product is minus (-)
   b. Arc less than 50 - Product is plus (+)


Cooperator - John Doe
Plane Table Topog
NW 1/4 SW 1/4 Sec. 31, Twp 164-R91
Weather - Clear & Cool
Date - 11, 26, '56
Farm No 10 Field No 4 ACP Ident 237
Survey Party
Jack Frost
John Jones
Location Map
R 91 W
31
B.M. El. 100.00
T 164 N
SW 1/4 Sec. 31
B.M. No. 1 - Nail in base of power line
Pole - N.W. corner of area topoged

FIELD NOTES FOR PLANE TABLE TOPOG
Figure 1.46-1

Dist.	Arc.	Prod	Rod	Diff.El.	El. ①
					100 00
635	52	-12 7	+ 3 5	- 9 2	
310	48	- 6 2	- 9 4	-15 6	75 2
350	50	0 0	- 3 5	- 3 5	87 3
720	56	+43 2	-11 5	+31 7	122 5
630	+ 1/2	+ 3 1	- 0 9	+ 2 2	93 0
720	- 1/2	- 3 6	-12 4	-16 0	74 8
415	53	+12 4	- 4 7	+ 7 7	98 5
640	47	+19 2	+11 4	+30 6	
460	51	+ 4 6	- 3 1	+ 1 5	130 6
720	50	0 0	- 9 4	- 9 4	119 7

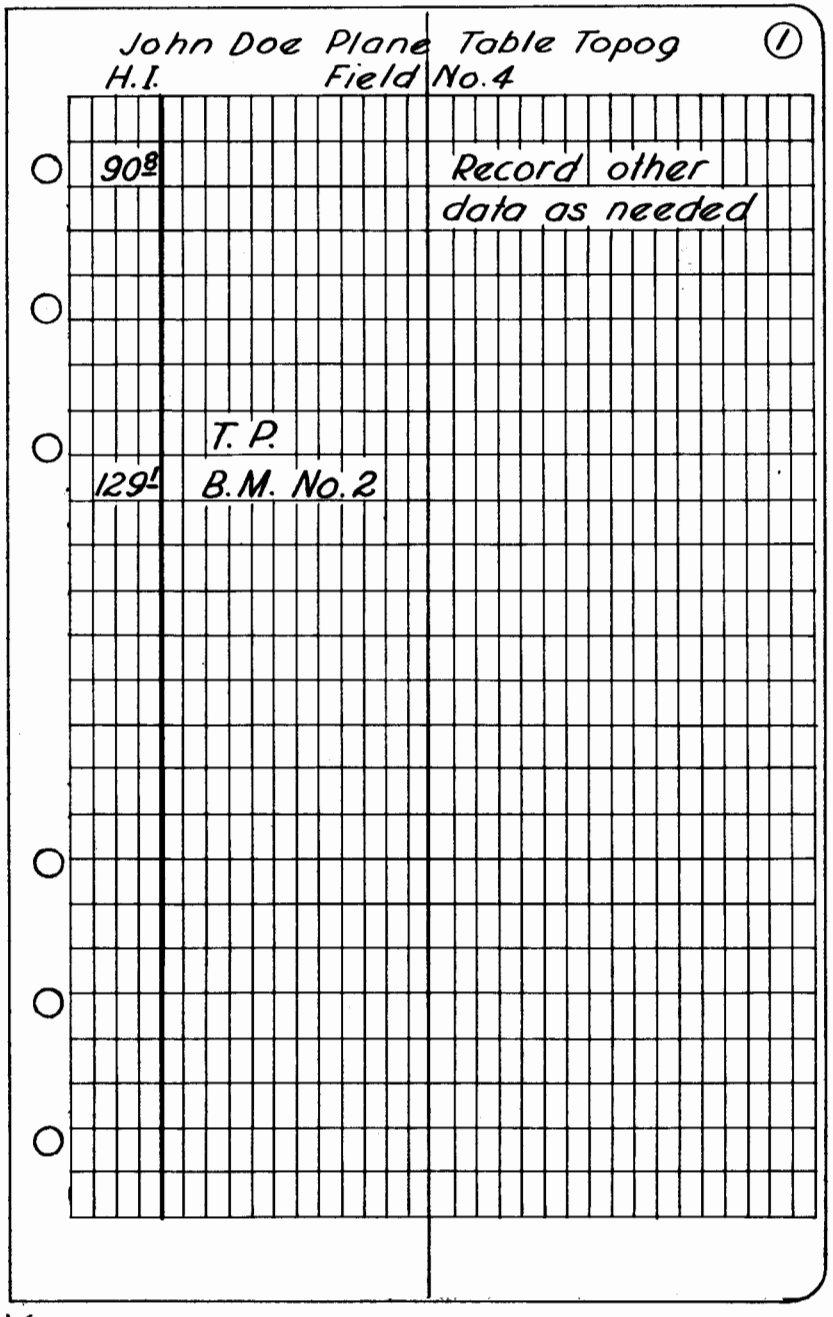


Figure 1.46-2

11. TYPES OF SURVEYS (CONT'D)

Beaman Stadia Arc (cont'd)

2. On fore sights.
   a. Arc more than 50 - Product is plus (+)
   b. Arc less than 50 - Product is minus (-)

For more detailed definition of back sights and foresights, see section of "Surveying Terms".

In some cases with telescope level the bottom or the top hair may be on the rod and the center and other outside hair off the rod. The telescope must be tilted enough to obtain the distance but then it can be brought back to level and the product determined by multiplying the distance by ½ or .5 and the sign determined by the same set of rules as stated above.

4th Column - Rod. The Beaman Arc is set on some even division so that the center cross hair falls on the rod. The rod reading is then the reading of the center cross hair on the rod.

The only exception of this will be on half Beaman Arc shots. The rod reading is then the rod reading of either the top or bottom cross hair.

The sign that applies to the rod reading is the same as in differential leveling. All back sights are plus (+) and all fore sights are minus (-).

5th Column - Difference of Elevation. The numerical value and sign of this item is the algebraic sum of column 3 and 4. For example, in the first line of the illustration column #3 = 12.7 and column #4 = +3.5 giving the difference of elevation of a -9.2.

6th and 7th Columns - Elevation or H.I. Beginning with an assumed elevation of 100° from bench mark #1. The first shot would be a back sight since we need to establish an H.I. before any subsequent elevations can be determined. The H.I. is determined by adding or subtracting the difference in elevation from the elevation of the bench mark. The sign of the difference in elevation would determine whether the number is to be added or subtracted. New elevations are established by adding or subtracting the difference of elevation from the H.I. in accordance with the sign of the difference in elevation. This procedure applies to all elevations established. A turning point can be taken on any new elevation established and a new H.I. determined by the same method as explained above.

Advantages of the Beaman Stadia Arc:

a. It eliminates the need for stadia tables, slide rules or diagrams.
b. There is no vernier to read.
c. Accuracy of results are identical with formula, or table computations.
d. Changes of errors are practically eliminated because of its simplicity.

11. TYPES OF SURVEYS (CONT'D)

Slope Staking. Slope stakes are set on the right and left of the centerline at the place where the finished slope (either cut or fill) intersects the original ground line. Setting slope stakes for earth fill and most all other types of jobs that involve earthwork, is part of a layout procedure that is widely used. Following is an example of setting slope stakes for open ditch, side spillway, dam and any other earthwork that requires placing or excavating earth of a predetermined slope.

a. Assume that an earth fill be staked with the following information given:

(1) Top width of dam - 8 feet
(2) Upstream side slope - 3:1
(3) Downstream side slope - 2:1
(4) Elevation of top of settled fill - 101.9'
(5) Location and elevation of bench mark
(6) Centerline of dam previously marked with appropriate stake (see profiles and cross sections).

b. Slope Staking Procedure

(1) Run levels from B.M. to point of convenience at dam sites and compute H.I. (102.42 - see field notes Figure 1.48).
(2) Compute difference between H.I. elevation and top of fill (102.42 - 101.9 = 0.5). This is grade rod at station 1+00.
(3) With centerline rod reading of 4.2 at station 1+00, compute elevation of ground surface, then compute fill height (101.9 - 98.2 = 3.7). This can be done also by merely subtracting the difference between H.I. and top of fill from the center line rod reading (4.2 - 0.5 = 3.7').
(4) The centerline fill has now been determined and to set the slope stakes at right angles to the centerline the surveyor must keep in mind side slope, top width, berm width, if any, and fill (or cut) at the centerline. The distance out from the centerline, at which a slope stake is correctly set, is given by the relationship, $d = \frac{w}{2} + hs$ where:

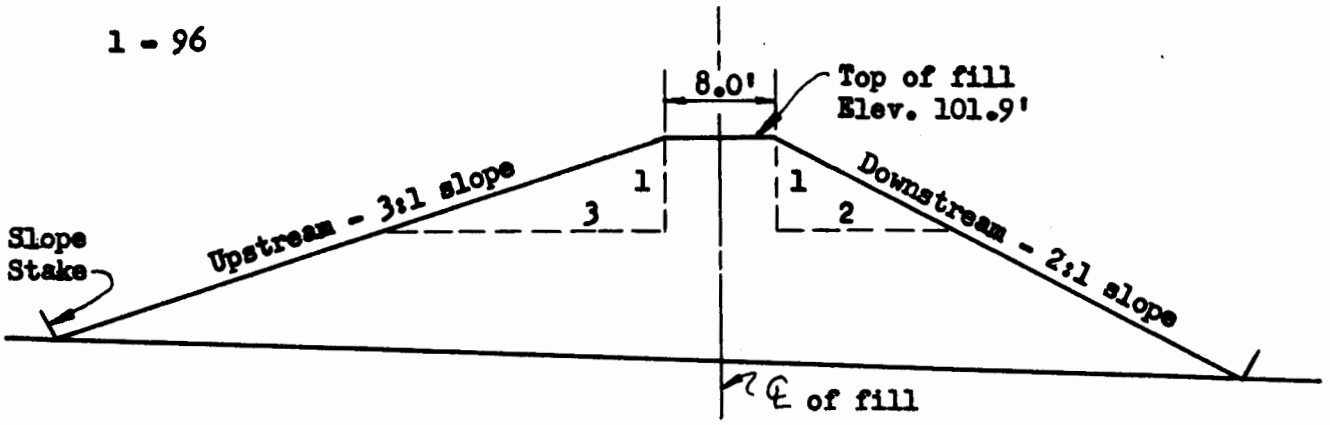
d = distance in feet w = top width in feet
h = fill (or cut) in feet s = side slope

Where berm is used the formula becomes $d = \frac{w}{2} + b + hs$,

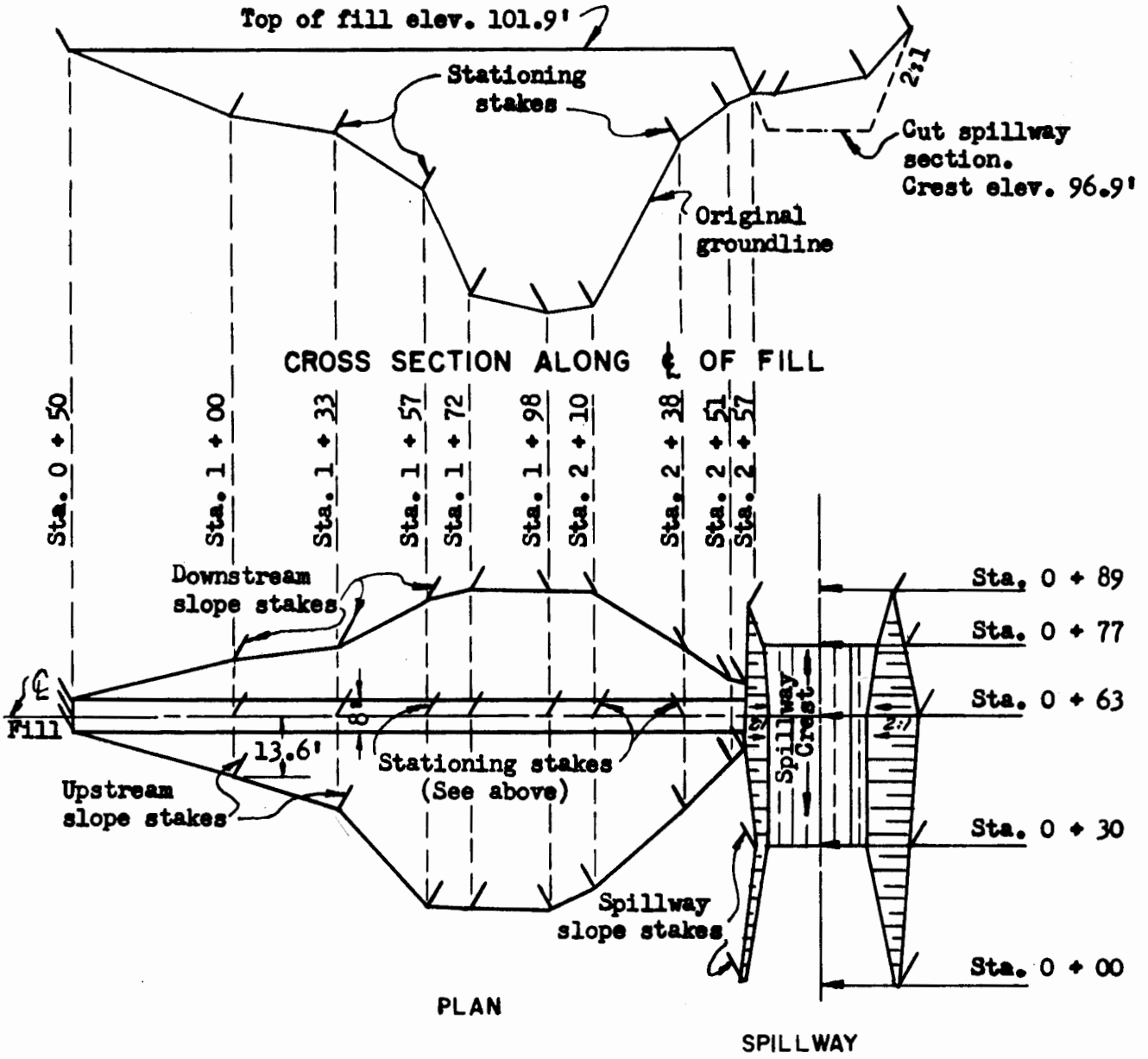
where:

b = berm width in feet

(5) For the first trial at setting a slope stake on the upstream side of the dam at station 1+00, measure a distance at right angles to the centerline stake of, $d = \frac{8}{2} + (4.2 \times 3) = 16.6$. Take a rod reading at this point. In the example the rod reading was



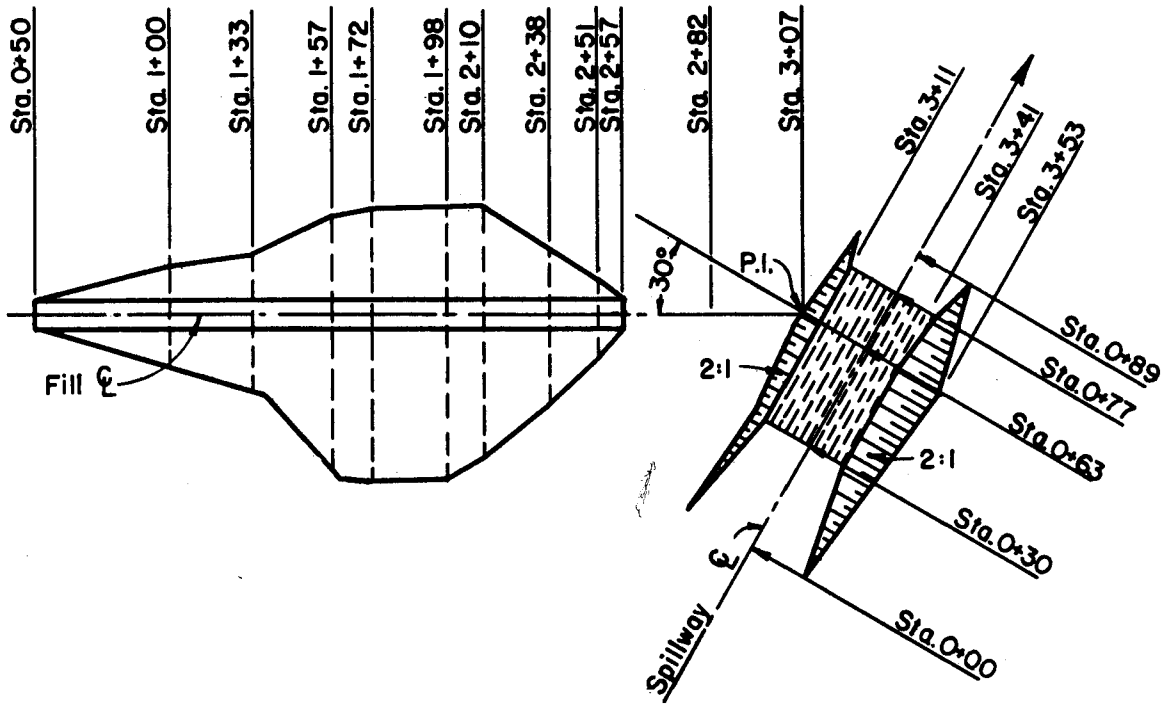
CROSS SECTION PERPENDICULAR TO ℄ OF FILL



LOCATION OF SLOPE STAKES

Figure 1.47

11. TYPES OF SURVEYS (CONT'D)



ALTERNATE SPILLWAY LOCATIONS

It may be necessary or desirable to place the cut spillway in a location other than at the end of the dam and perpendicular to the dam centerline as is shown in Figure 1.47. The spillway may be offset from the dam, placed at some angle to the dam centerline, or may be curved. Some reasons for adjusting the spillway location are:

1. Better material available for the spillway or dam fill.
2. Better spillway entrance or exit conditions.
3. Lower yardage or more economical yardage.

Figure 1.47-1 illustrates an example of spillway location and orientation with respect to the dam centerline. Figure 1.48-4 shows field notes for this example.

Figure 1.47-1

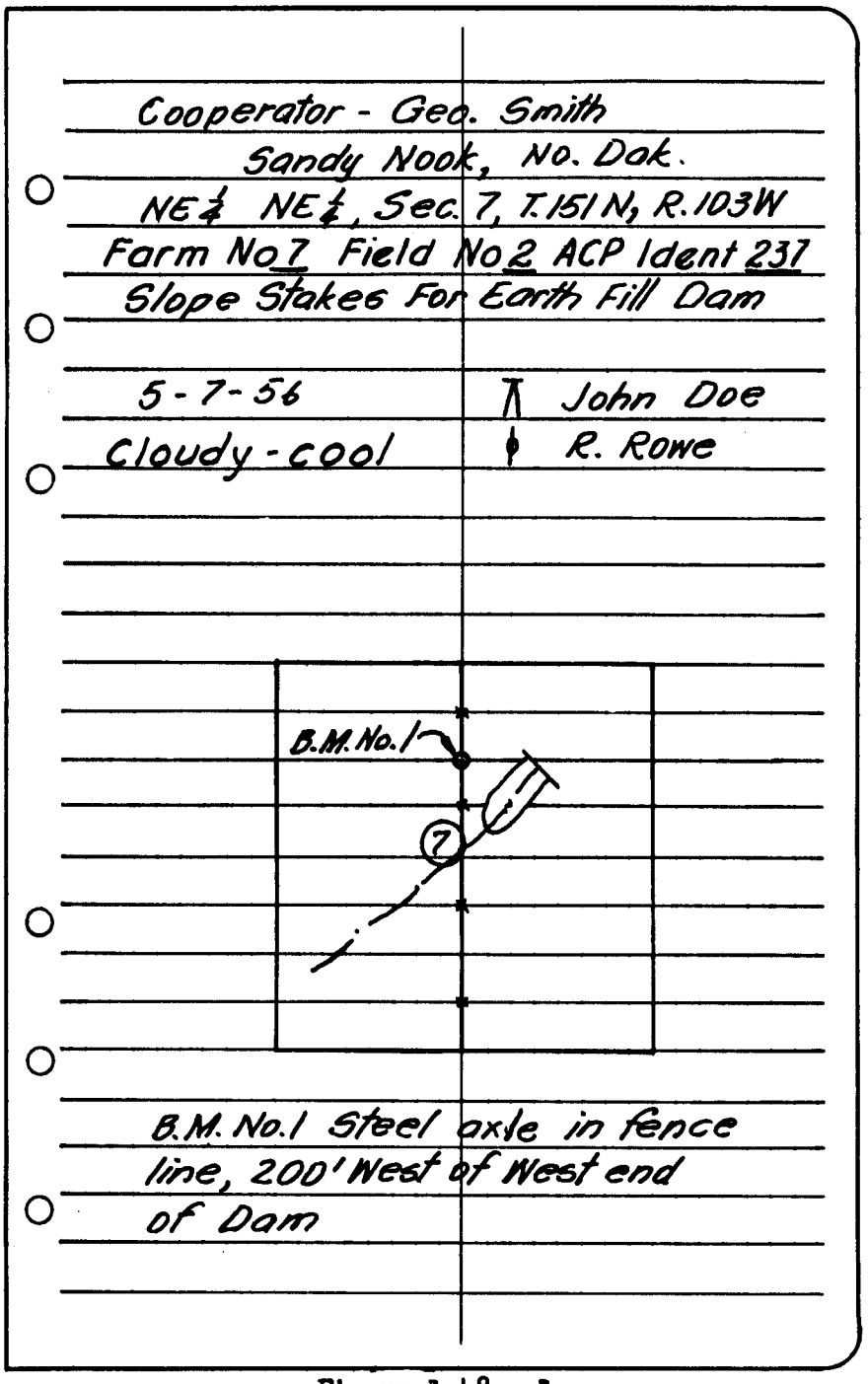

Cooperator - Geo. Smith
Sandy Nook, No. Dak.
NE¼ NE¼, Sec. 7, T. 151 N, R. 103W
Farm No 7 Field No 2 ACP Ident 237
Slope Stakes For Earth Fill Dam
5-7-56
Cloudy - cool
John Doe
R. Rowe
B.M. No. 1
7
B.M. No. 1 Steel axle in fence line, 200' West of West end of Dam

Figure 1.48 - 1

Sta.	B.S.	H I.	Grade rod or F.S.	Grade El. or El.	Shrinkage
B.M.-1	2.42			100.00	
		102.42			
0+50 W. end Dam			- 0.5	101.9	0.0
1+00			-0.5	101.9	0.4
1+33			-0.5	101.9	0.5
T.P.1	0.89		(8.19)	(94.23)	
		95.12			
1+57			+6.8	101.9	0.8
1+72			+6.8	101.9	1.5
1+98			+6.8	101.9	1.6
2+10			+6.8	101.9	1.5
T.P.2	4.50	104.84	(1.78)	(93.34)	
2+38			-2.9	101.9	0.5
2+51			-2.9	101.9	0.3
End of Dam 2+57			- 5.9	98.9	0.0

Geo Smith Slope Stakes For Dam Field No. 2

Steel axle in fence line 200' West of West end of Dam.

	Downstream 2:1		Upstream 3:1
	0.5	0.5	0.5
	F=0.0-4'	F=0.0	F=0.0-4'
	5.0	4.2	3.7
	F 4.5-13.0'	3.7	F3.2-13.6'
	6.1	5.7	6.3
	F 5.6-15.2'	5.2	F=5.8-21.4'
H			
8.19	8.0	1.6	7.2
100	F=14.8-33.6'	F=8.4	F=14.0-46.0'
	9.4	8.1	7.3
	F=16.2-36.4	F=14.9'	F=14.1-46.3'
	9.2 86.9	4.3 90.8	8.7 86.4 7.6 87.5
	F=16.0-36.0	20'	F=15.5 F=14.4-47.2
	9.2	8.3	6.2
	F=16.0-36.0'	F=15.1	F=13.0-43.0'
	10.7	8.3	9.2
	F=7.8-19.6'	F=5.4	F=6.2-22.9'
	6.5	6.2	6.4
	F=3.6-11.2	F=3.3	F=3.6-14.5
	5.9	5.9	5.9
	F=0.0-10.0'	F=0.0	F=0.0-13.0'

Figure 1.48 - 2

Sta.	B.S.	H.I.	Grade rod or F.S.	Grade El. or El.	Shrinkage.
		104.84			
Inside edge of spillway 2+59			-5.9	98.9	—
Inside bottom of spillway 2+63			-7.9	96.9	—
Outside bottom of spillway 2+93			-7.9	96.9	—
Outside edge of spillway 3+064			-1.2	103.6	—
	Slope stakes spillway				
B.M.-1			4.82	(100.02)	Error - 0.02
Corrected H.I.		104.82			Bottom width
0+00			-8.8	96.0	44'
0+30			-7.9	96.9	30'
Spillway 0+63 Crosses ℄ Dam @ 2+18			-7.9	96.9	30'
0+77			-7.9	96.9	34'
0+89			-7.9	96.9	42'
B.M.-1			(4.82)	(100.00)	

Geo Smith Slope Stakes For Dam Field No. 2.

Across spillway on ℄ Roadway. Slope stakes shown

℄		
5.7 C=0.2		
5.6 C=2.3		
4.8 C=3.1		
1.2 C=0.0		

Slope stakes spillway

Described page 1. Rt & Lt looking downstream

2:1 Left	℄	2:1 Right
8.8 C=0.0-22'	8.5 C=0.3	8.8 C=0.0-22'
7.1 C=0.8-16.6'	6.6 C=1.3	4.2 C=3.7-22.4'
5.7 C=2.2-19.2'	5.2 C=2.7	1.2 C=6.7-28.4'
6.7 C=1.2-19.4'	6.8 C=1.1	4.7 C=3.2-23.4'
7.9 C=0.0-21'	7.9 C=0.0	7.9 C=0.0-21'

Figure 1.48 - 3

Sta	B.S.	H.I.	Grade rod or F.S.	Grade El. or El.	Shrink-age
		104.84			
2+57	End of dam		-5.9	98.9	
2+82			-5.9	98.9	
P.I. 3+07	30° Right (Approx) Inside Edge of Spillway		-5.9	98.9	
3+11	Inside Bottom of Spillway		-7.9	96.9	
3+41	Outside Bottom of Spillway		-7.9	96.9	
3+53	Outside Edge of Spillway		-1.2	103.6	
	SLOPE STAKES SPILLWAY				
B.M.-1	4.82			100.00	
		104.82			
0+00			-8.8	96.0	
		ETC.			
	See Figure 1.48-3				

Across Spillway, 90° To Center Line of Spillway — On Center Line of Dam

5.9 / C 0.0
5.6 / C 0.3
5.7 / C 0.2
5.6 / C 0.3
4.8 / C 3.1
1.2 / C 0.0

P.I. 30° RT.

SLOPE STAKES SPILLWAY

Described Page 1

RT. & LT. Looking Downstream

2:1 Left

8.8 / C = 0.0 - 22'

2:1 Right

8.5 / C 0.3

8.8 / 0.0 + 22'

ETC.

See Figure 1.48-3

Figure 1.48-4

11. TYPES OF SURVEYS (CONT'D)

Slope Staking (cont'd)

3.7 which gave a distance of $d = \frac{8}{2} + (3.7-0.5) \times 3 = 13.6$.

By moving the rod from 16.6 to 13.6 feet from the centerline it was found that the rod reading again was 3.7; so the stake was put in and marked. (See Figures 1.47 and 1.48 allowance for settlement shall be marked on the slope stake.) The distance, rod reading and elevation is recorded in the field book.

(6) Slope staking is a cut and try method. Practice will develop judgement in making distance adjustments so that a minimum of trials will be necessary to find the location to put the slope stake. The same procedure is used to find the downstream slope stake at station 1+00 and the stakes at the other stations.

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES

Stock Water Dams

After the selection of the dam site, proceed with the survey as follows:

Design Surveys.

a. Set instrument at some point which will allow the taking of all necessary information without resetting, if possible.
b. Establish bench mark and assign elevation. Bench mark should be located to insure accessibility and where it will be unmolested by machinery.
c. Establish station 0+00 at the end of the dam on the left bank of the draw when facing downstream and far enough away to include the spillway should it be located there.
d. Set stakes on the centerline at regular intervals (stations) and at plus stations when breaks occur in the ground line. All measurements should be made with the tape held level.
e. Run profile levels along the centerline and take cross sections at each station and plus station at right angles to the proposed dam centerline.
f. Record top width, top elevation, upstream and downstream slopes of dam, spillway crest elevation and bench mark location in field notes. (See sample notes Figure 1.48).

Use Stockwater dam Data Sheet:

a. Show drainage area in acres. This can usually be obtained from aerial photographs.
b. Show peak discharge.
c. Plot profile of dam site and show height, side slopes and top width.
d. Plot maximum cross section of dam site and cross section of spillway.

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

Stockwater Dams (cont'd)

e. Record log of soil borings, if needed. If plan sheet is used in field, the log of the borings may be plotted directly on the profile taken on centerline of dam, in which case data would not be recorded in field notebook.

f. Vegetated spillway.

(1) Cut spillway

(a) Show depth of water in reservoir above spillway crest H.
(b) Show discharge "Q" in c.f.s.
(c) Show bottom width and side slopes.

(2) Natural Spillway

(a) Show cross-sectional area at flow depth.
(b) Show top width at flow depth.
(c) Show mean depth.
(d) Show discharge "Q" in c.f.s.

(3) Show profile of spillway when necessary in design.

g. Mechanical Spillway

(1) Show size and capacity.
(2) Show elevation of inlet and outlet.
(3) Sketch cross section of dam in space provided.
(4) Show quantities of pipe and concrete.

h. Water supply system

(1) Sketch on cross section of dam.
(2) Show estimated quantities.

i. Show approximate surface area of pond and estimate storage capacity.

(1) If stage-storage curve is required, a topographic survey should be made of the reservoir area.

j. Show location of dam to nearest 40 acres subdivision.

k. For dams over 25' in height sketch plan of dam spillway and reservoir. (See Figure 1.49)

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

Layout Survey

a. Slope Stakes - see section Slope Staking
b. Record notes for alignment and grade stakes set for mechanical spillway and water supply system, where used.
c. Compute yardage in fill. Use standard earthwork computation tables, or earthwork computation sheets if berms are involved.

Grade Stabilization Structures. To properly design a gully control structure specific survey data is necessary. The amount of detail required will depend on the size and complexity of the structure. Generally, the following outlined procedure will provide the data necessary for design.

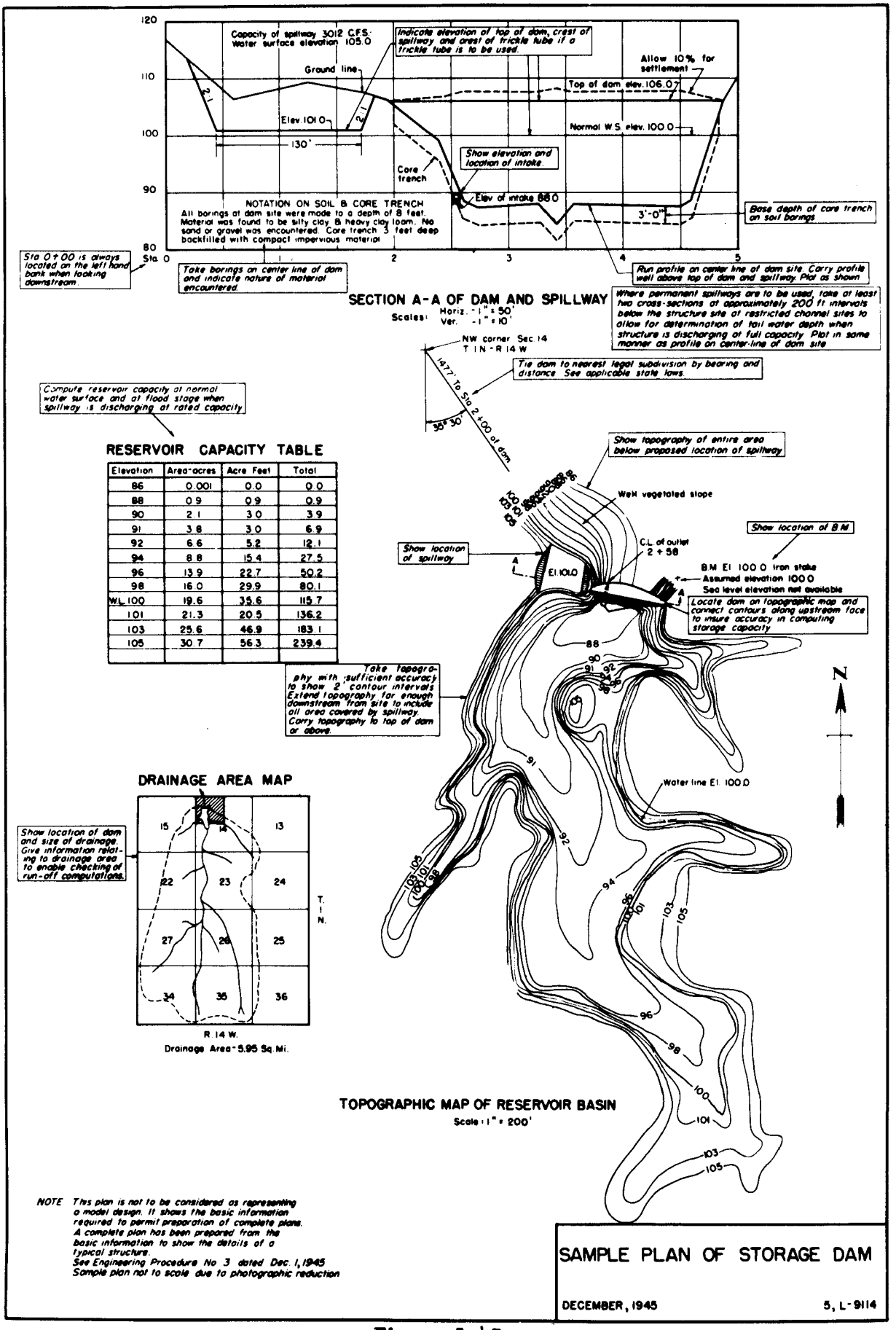
Design.

a. Use field notebook.

(1) Record bench marks. Describe fully and assign elevation.
(2) Record survey notes for profile of gully bottom and banks as needed for design.
(3) Record survey notes for profile of dam site. Usual practice is to combine the taking of the profile with the survey made for establishing slope stakes.
(4) Record survey notes for the cross sections of gully, as needed for determination of tailwater elevation.
(5) Record survey notes for such topographic information as is needed for design. Grades downstream, overfalls, and channel characteristics are important items.
(6) Describe condition of natural or cut spillway, or take profile and cross section on centerline and record notes.

b. Use Grade Stabilization Data Sheet:

(1) Show drainage area in acres.
(2) Show peak discharge.
(3) Plot profiles and cross sections.
(4) Record log of soil borings, if needed in design. If standard plan sheet is used in field, the log of borings may be plotted directly on the profile of dam centerline. If this is done data need not be recorded in notebook.
(5) Vegetated Spillway.
  (a) Cut Spillway
    (aa) Show depth of flow above spillway crest (H).
    (bb) Show discharge "Q" in c.f.s.
    (cc) Show bottom width and side slopes.
  (b) Natural Spillway
    (aa) Show cross-sectional area at flow depth
    (bb) Show top width at flow depth.
    (cc) Show mean depth
    (dd) Show discharge "Q" in c.f.s.


Capacity of spillway 3012 C.F.S.
Water surface elevation 105.0
Indicate elevation of top of dam, crest of spillway and crest of trickle tube if a trickle tube is to be used.
Allow 10% for settlement
Ground line
Top of dam elev. 106.0
Elev. 101.0
Normal W.S. elev. 100.0
130'
Show elevation and location of intake
Core trench
Elev. of intake 88.0
3'-0"
Base depth of core trench on soil borings
NOTATION ON SOIL & CORE TRENCH
All borings at dam site were made to a depth of 8 feet. Material was found to be silty clay & heavy clay loam. No sand or gravel was encountered. Core trench 3 feet deep backfilled with compact impervious material
Sta. 0+00 is always located on the left hand bank when looking downstream.
Take borings on center line of dam and indicate nature of material encountered.
Run profile on center line of dam site. Carry profile well above top of dam and spillway. Plot as shown
SECTION A-A OF DAM AND SPILLWAY
Scales: Horiz. - 1" = 50'
Ver. - 1" = 10'
Where permanent spillways are to be used, take at least two cross-sections at approximately 200 ft intervals below the structure site at restricted channel sites to allow for determination of tail water depth when structure is discharging at full capacity. Plot in same manner as profile on center line of dam site
NW corner Sec. 14
T. 1 N. - R. 14 W.
1477' to Sta. 2+00 of dam
35° 30'
Tie dam to nearest legal subdivision by bearing and distance. See applicable state laws.
Compute reservoir capacity at normal water surface and at flood stage when spillway is discharging at rated capacity
RESERVOIR CAPACITY TABLE
Show topography of entire area below proposed location of spillway
Well vegetated slope
Show location of B.M.
Show location of spillway
C.L. of outlet 2 + 58
El. 101.0
B.M. El. 100.0 Iron stake
Assumed elevation 100.0
Sea level elevation not available
Locate dam on topographic map and connect contours along upstream face to insure accuracy in computing storage capacity
Take topography with sufficient accuracy to show 2' contour intervals. Extend topography far enough downstream from site to include all area covered by spillway. Carry topography to top of dam or above.
N
Water line El. 100.0
DRAINAGE AREA MAP
Show location of dam and size of drainage. Give information relating to drainage area to enable checking of run-off computations.
T. 1 N.
R. 14 W.
Drainage Area - 5.95 Sq. Mi.
TOPOGRAPHIC MAP OF RESERVOIR BASIN
Scale: 1" = 200'
NOTE: This plan is not to be considered as representing a model design. It shows the basic information required to permit preparation of complete plans. A complete plan has been prepared from the basic information to show the details of a typical structure.
See Engineering Procedure No. 3 dated Dec. 1, 1945
Sample plan not to scale due to photographic reduction
SAMPLE PLAN OF STORAGE DAM
DECEMBER, 1945
5, L-9114

Elevation	Area-acres	Acre Feet	Total
86	0.001	0.0	0.0
88	0.9	0.9	0.9
90	2.1	3.0	3.9
91	3.8	3.0	6.9
92	6.6	5.2	12.1
94	8.8	15.4	27.5
96	13.9	22.7	50.2
98	16.0	29.9	80.1
WL 100	19.6	35.6	115.7
101	21.3	20.5	136.2
103	25.6	46.9	183.1
105	30.7	56.3	239.4

Figure 1.49

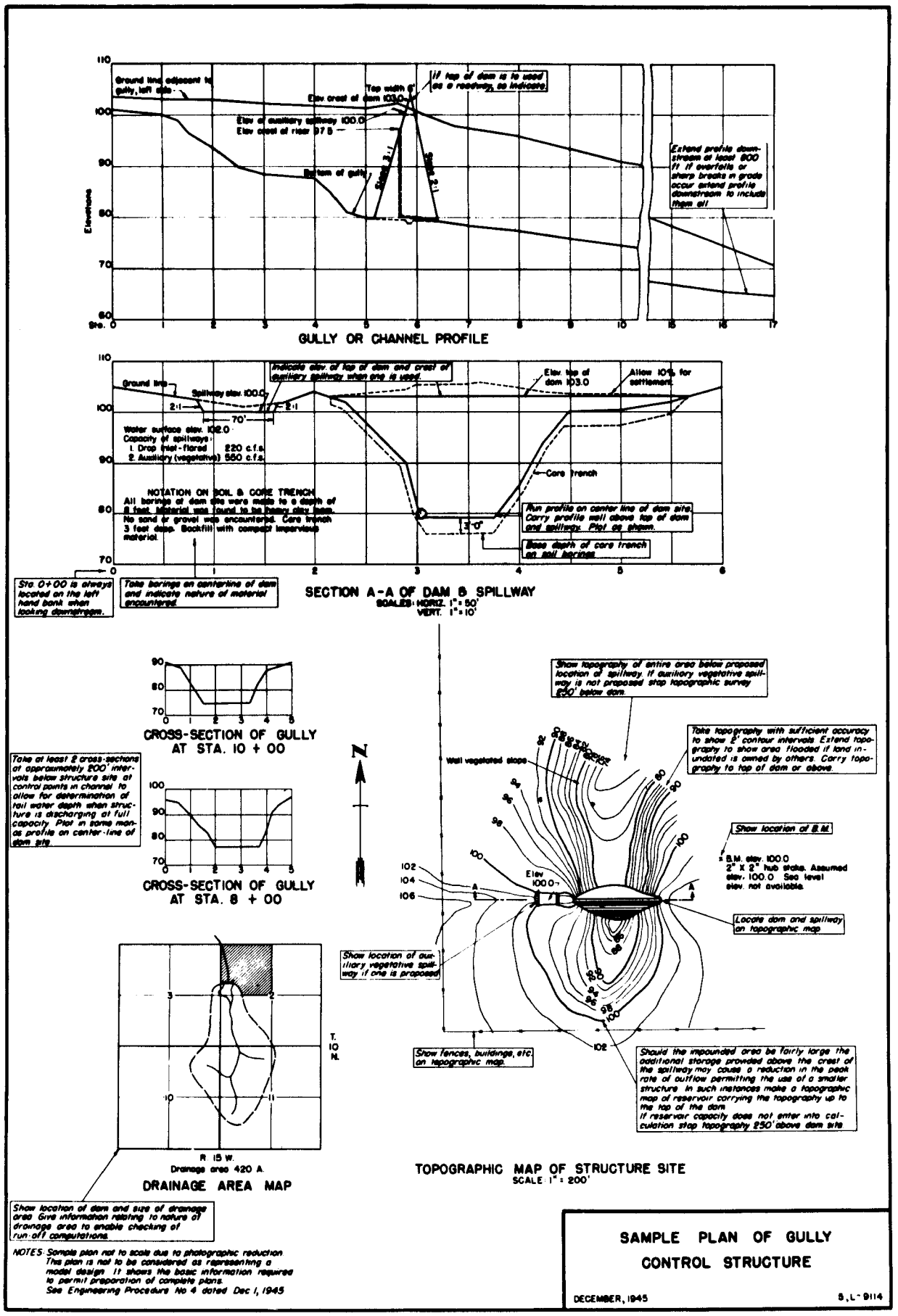

GULLY OR CHANNEL PROFILE
Ground line adjacent to gully, left side
Top width 6'
Elev crest of dam 103.0
Elev of auxiliary spillway 100.0
Elev crest of riser 97.5
Bottom of gully
Slope 2:1
Slope 2:1
Elevations
Sta. 0
If top of dam is to used as a roadway, so indicate
Extend profile downstream at least 800 ft if overfalls or sharp breaks in grade occur extend profile downstream to include them all
SECTION A-A OF DAM 8 SPILLWAY
SCALES: HORIZ. 1" = 50'
VERT. 1" = 10'
Ground line
Spillway elev. 100.0
Indicate elev. of top of dam and crest of auxiliary spillway when one is used
Elev. top of dam 103.0
Allow 10% for settlement
2:1
2:1
70'
Water surface elev. 102.0
Capacity of spillways:
1. Drop (rect.-flared) 220 c.f.s.
2. Auxiliary (vegetative) 560 c.f.s.
Core trench
NOTATION ON SOIL & CORE TRENCH
All borings at dam site were made to a depth of 8 feet. Material was found to be heavy clay loam. No sand or gravel was encountered. Core trench 3 feet deep. Backfill with compact impervious material.
3'-0"
Run profile on center line of dam site. Carry profile well above top of dam and spillway. Plot as shown.
Base depth of core trench on soil borings
Sta. 0+00 is always located on the left hand bank when looking downstream.
Take borings on centerline of dam and indicate nature of material encountered
CROSS-SECTION OF GULLY AT STA. 10 + 00
CROSS-SECTION OF GULLY AT STA. 8 + 00
Take at least 2 cross-sections at approximately 200' intervals below structure site at control points in channel to allow for determination of tail water depth when structure is discharging at full capacity. Plot in same manner as profile on center-line of dam site.
N
Show topography of entire area below proposed location of spillway. If auxiliary vegetative spillway is not proposed stop topographic survey 250' below dam.
Take topography with sufficient accuracy to show 2' contour intervals. Extend topography to show area flooded if land inundated is owned by others. Carry topography to top of dam or above.
Wall vegetated slope
Show location of B.M.
B.M. elev. 100.0
2" X 2" hub stake. Assumed elev. 100.0 Sea level elev. not available.
Elev 100.0
Locate dam and spillway on topographic map
Show location of auxiliary vegetative spillway if one is proposed
Show fences, buildings, etc. on topographic map
Should the impounded area be fairly large the additional storage provided above the crest of the spillway may cause a reduction in the peak rate of outflow permitting the use of a smaller structure. In such instances make a topographic map of reservoir carrying the topography up to the top of the dam. If reservoir capacity does not enter into calculation stop topography 250' above dam site
TOPOGRAPHIC MAP OF STRUCTURE SITE
SCALE 1" = 200'
R. 15 W.
T. 10 N.
Drainage area 420 A.
DRAINAGE AREA MAP
Show location of dam and size of drainage area. Give information relating to nature of drainage area to enable checking of run-off computations.
NOTES: Sample plan not to scale due to photographic reduction
This plan is not to be considered as representing a model design. It shows the basic information required to permit preparation of complete plans.
See Engineering Procedure No 4 dated Dec 1, 1945
SAMPLE PLAN OF GULLY CONTROL STRUCTURE
DECEMBER, 1945
S.L.-9114

Figure 1.50

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

Design (cont'd)

(6) Mechanical Spillway
- (a) Show size
- (b) Show elevations of inlet and outlet.
- (c) Sketch cross section in space provided.
- (d) Show quantities of materials.
- (e) Show discharge "Q" in c.f.s.

(7) Complete reservoir data table when storage is a factor.
(8) Show location of dam to nearest 40 acre subdivision.
(9) Sketch plan of dam spillway and reservoir (See Figure 1.50)
(10) Fill in flood routing data when spillway storage is a factor.

Layout

a. Use field notebook.

(1) Take standard slope stake notes for dam and spillway (see Slope staking).
(2) Record notes for alignment and grade stakes for mechanical spillway structure.
(3) Compute yardage in fill.

Large Open Ditch Surface Drains.

Design Surveys. Surveying for large open ditch drainage systems requires the gathering of all field data which will influence the design of the drain. This data may include field inspection of bridges, culverts, roads, existing drains and, of course, the outlet for the proposed drain. In many cases instrument work will be necessary to furnish the designer with enough information to determine a procedure to follow in making the actual survey, thus saving time on the overall job. This phase of the survey which is the PRELIMINARY INVESTIGATION is very important, and will furnish the designer an idea of scope and feasibility.

Determine Watershed Area. The watershed area may usually be outlined by the use of aerial photos, U. S. Geological Survey, or U. S. Coast and Geodetic Survey maps. Roads, bridges, culverts, and railroad locations may be checked also. In flat areas where sufficient data cannot be secured in this manner, it may become necessary to take levels in the area to determine the watershed boundary. This is usually done by taking shots at each quarter mile on a grid survey and at points where definite risers or depressions occur.

Establish Circuit of Bench Marks.

a. Run a closed level circuit over the route of the proposed ditch line. Establish bench marks often enough to provide a means to check elevations as survey progresses and to check construction. Check bench marks to accuracy of .05 ft. $\times\sqrt{\text{miles of traverse.}}$

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

Establish Circuit of Bench Marks (cont'd)

b. Tie this survey to sea level datum whenever possible. If a tie cannot be made to a U. S. Geological Survey of U. S. Coast and Geodetic Survey bench mark, or some other sea level datum, an assumed elevation should be selected at the starting point.
c. Use the form of notes shown in Figure 1.27.

Establish Survey Line.

a. The survey line should be run on or parallel to the centerline of the ditch whenever possible (See Figures 1.51 and 1.52)
b. An offset survey line may often facilitate the survey and construction.
c. Tie in the survey line to reference points at intervals to provide means of relocating lost stakes.
d. Take all topography and detail which will influence the design and construction of the ditch. Indicate the station on the line and the distance measured right or left of the survey line. Items to include are:

(1) Fence lines
(2) Culverts and bridges (size and type)
(3) Roads and railroads
(4) Telephone and transmission lines
(5) Buildings
(6) Land use
(7) Trees and brush
(8) Low areas on each side of survey line
(9) Any other features which may affect design or construction

e. Show deflection angles and plus readings at points of deflection
f. Use form of notes shown in Figure 1.51.

Profile over Ditch Line.

a. Determine elevations of natural ground at each 100 foot station and plus station wherever a break in grade occurs.
b. When ditch parallels a highway, take level shots on ground surface on each side.
c. Indicate elevations and approximate area of low fields adjoining ditch and also those some distance away. Give station and distance right or left of survey line.
d. Determine elevations of bottom of any existing ditch. (This may be taken from cross section survey if cross sections are taken at 100 foot intervals.)
e. Determine elevation of the bottom of all existing bridges and culverts.
f. Check profile elevations with bench marks along route.
g. Use form of notes shown in Figure 1.28.

TRAVERSE NOTES - LARGE DRAINAGE DITCH

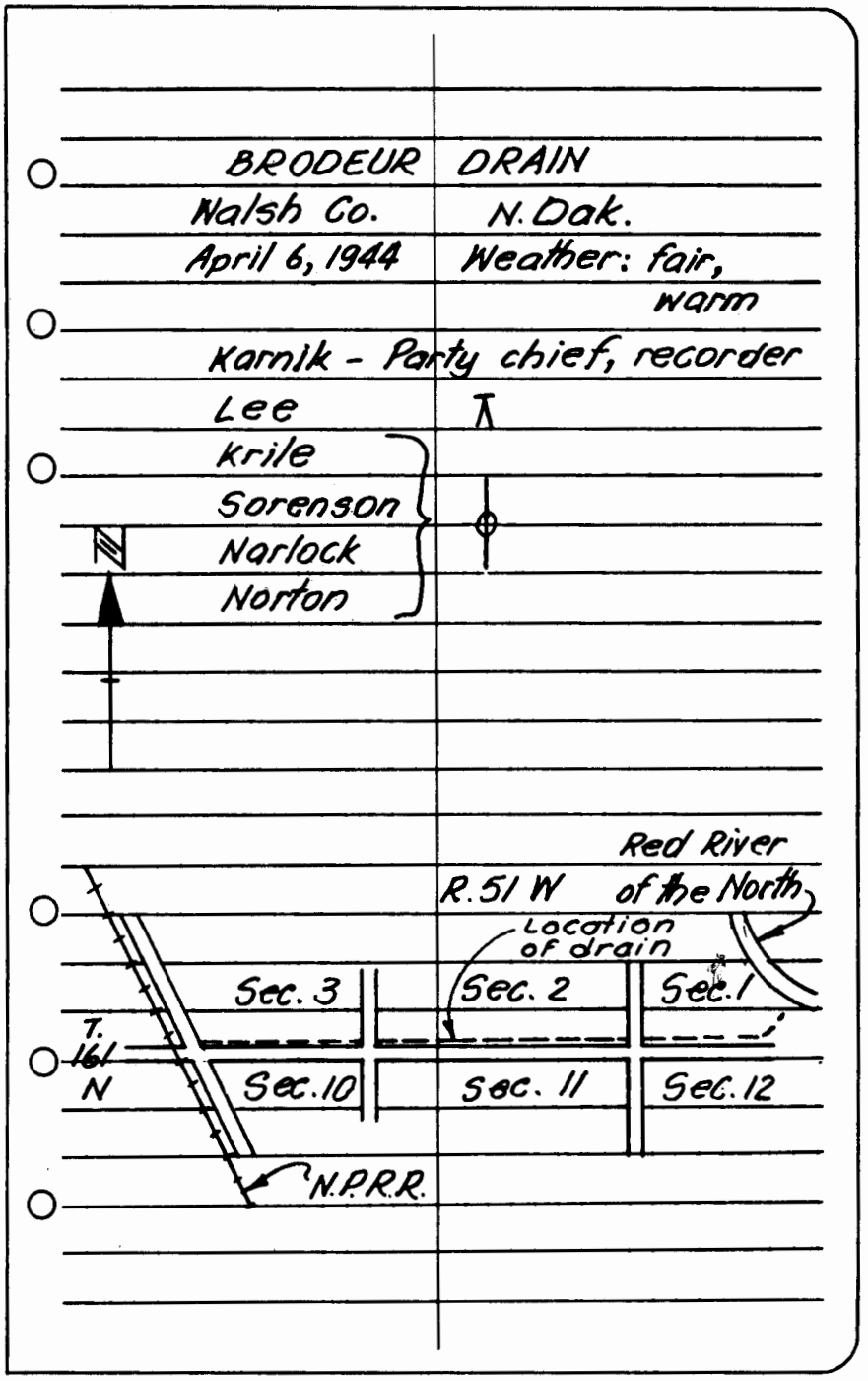


Figure 1.51

TRAVERSE NOTES - LARGE DRAINAGE DITCH

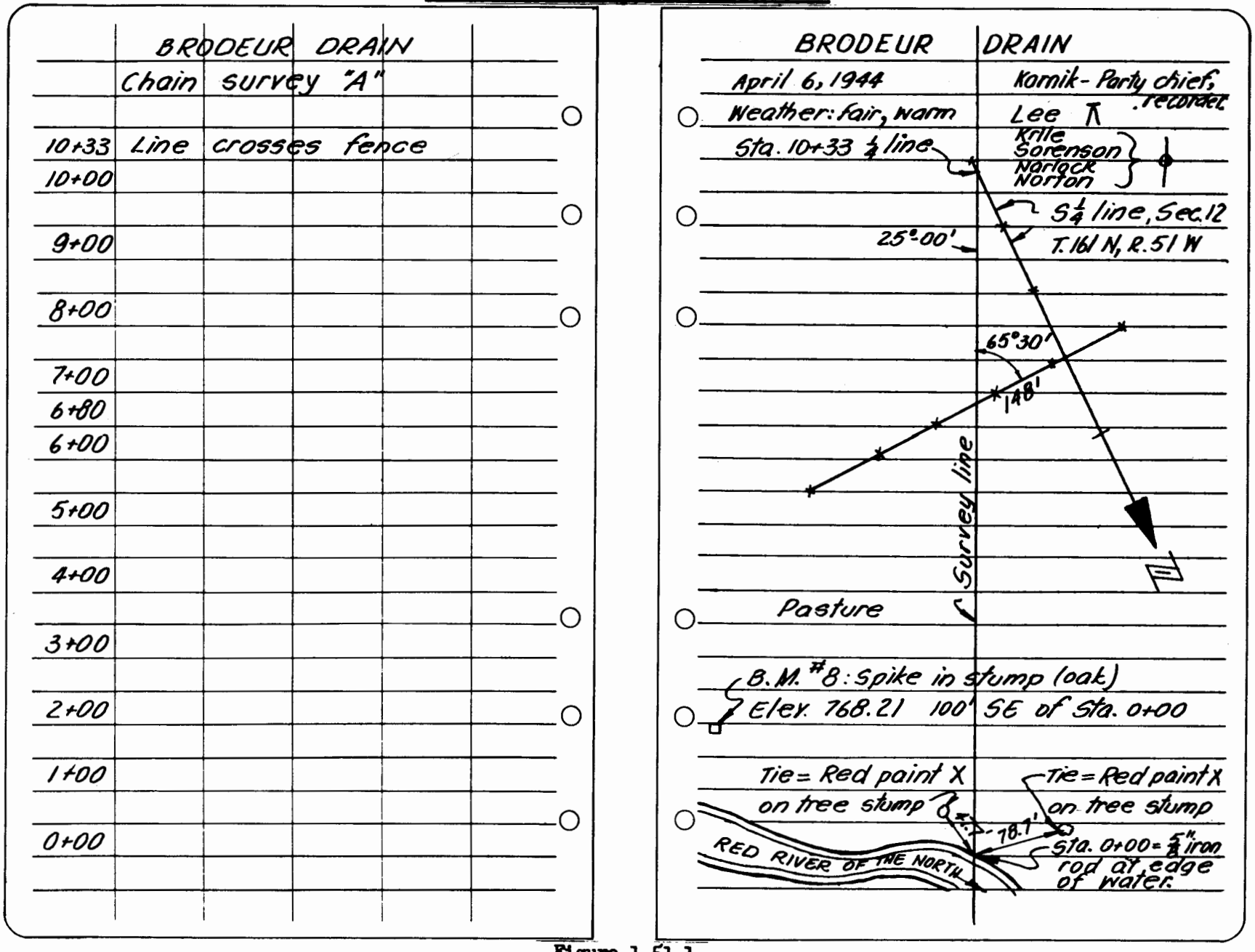


Figure 1.51-1

TRAVERSE NOTES - LARGE DRAINAGE DITCH

(2)

BRODEUR DRAIN CONT.

22+00	
21+00	
20+00	
19+00	
18+00	
17+00	
16+43	Private driveway
16+00	
15+00	
14+00	
13+25	18"x 20' C.M.P.
13+00	
12+00	
11+50	66°-02'R (End of road)
11+00	

BRODEUR DRAIN (2)

Some party April 7, 1954

Weather

Cool windy

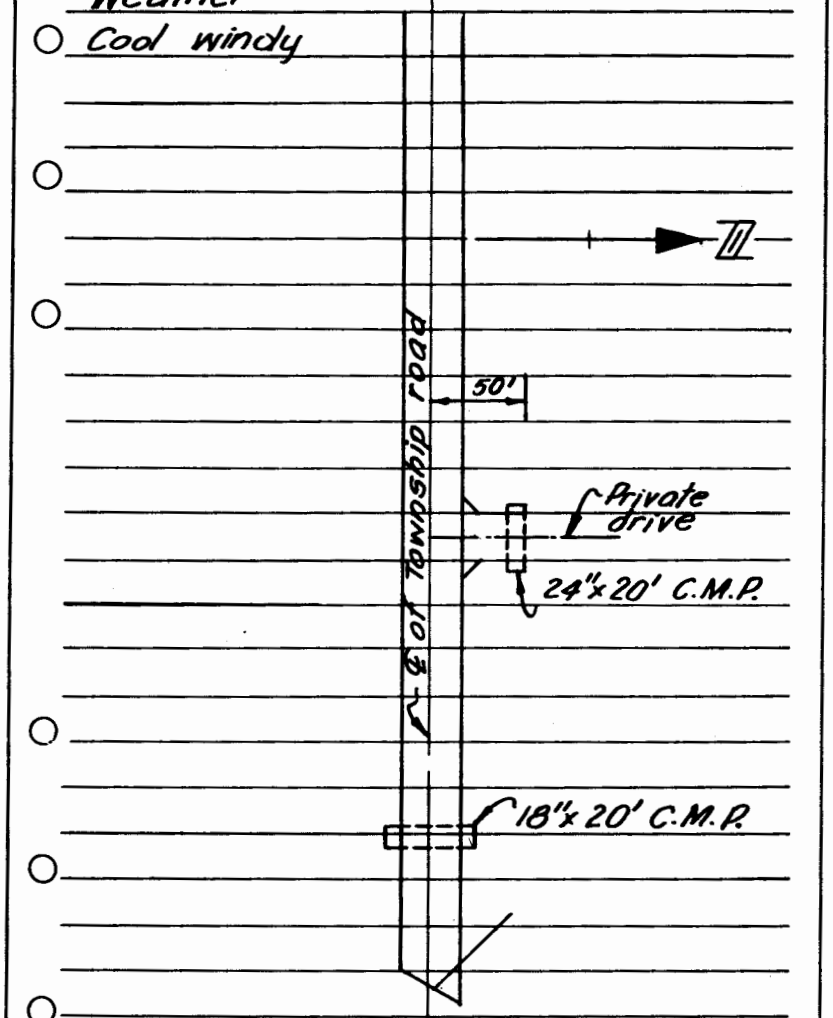
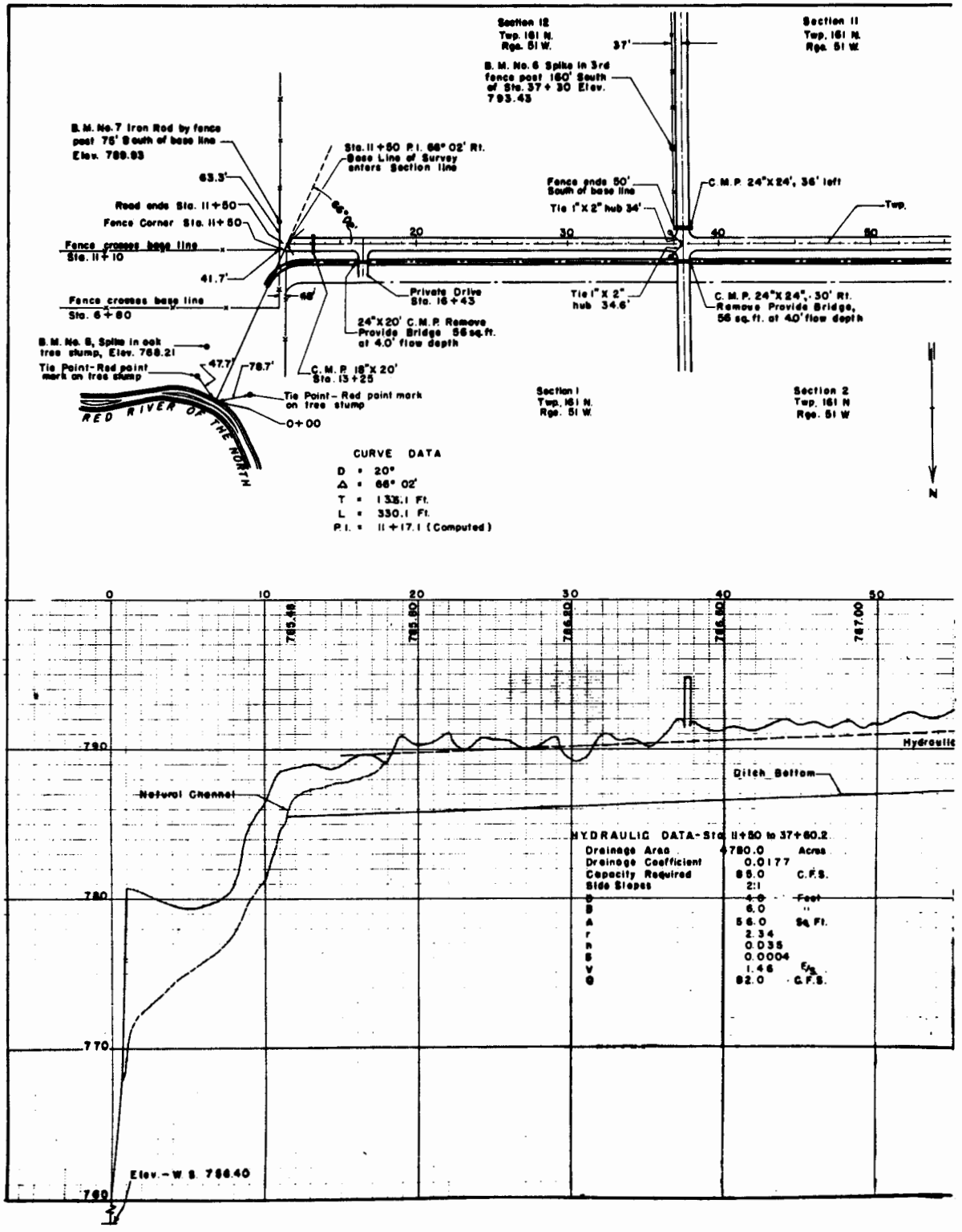
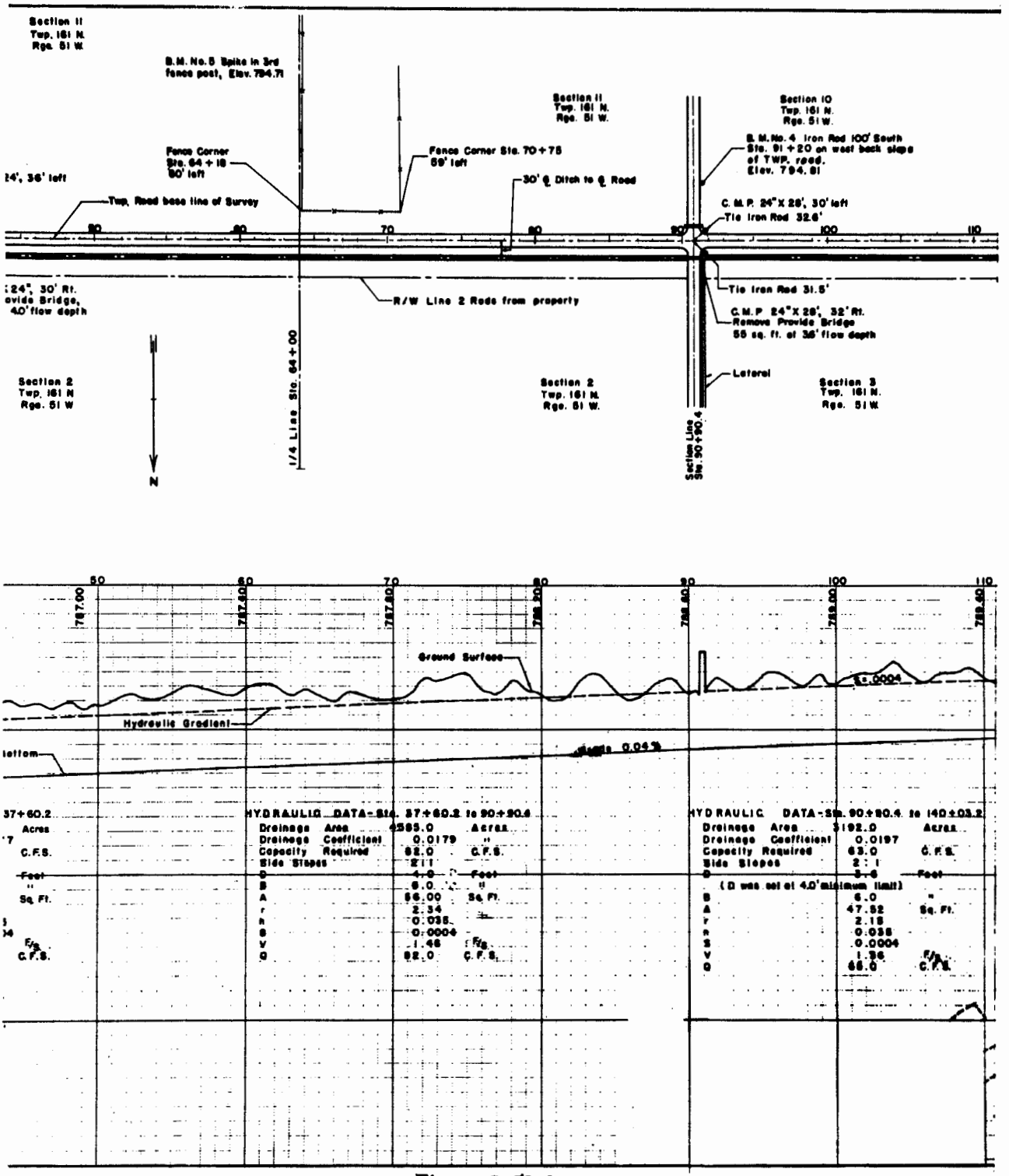


Figure 1.51-2



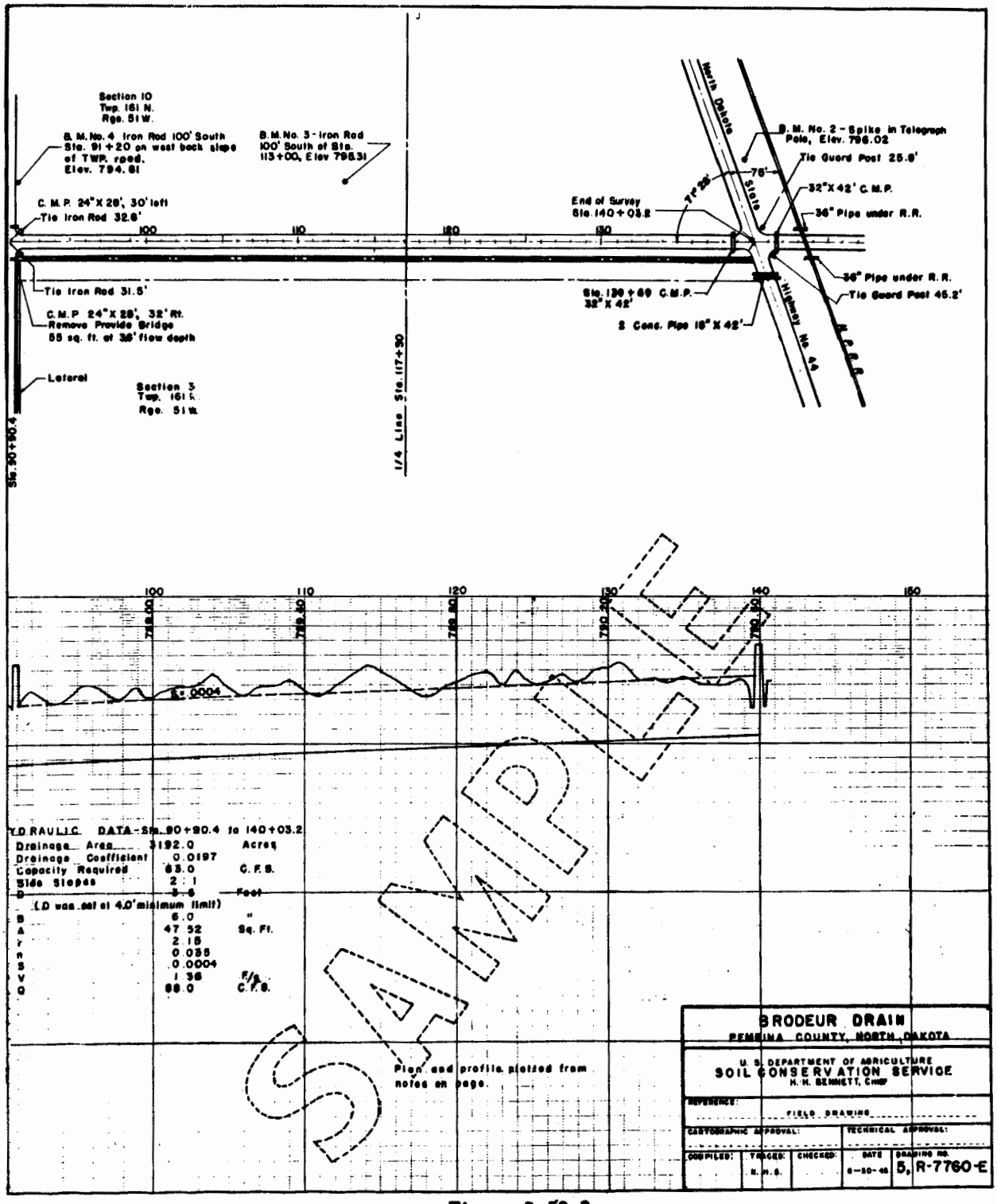
SAMPLE PLAN LARGE DRAINAGE DITCH

Figure 1.52-1


Section 11
Twp. 161 N.
Rge. 51 W.
B.M. No. 5 Spike in 3rd fence post, Elev. 794.71
Fence Corner Sta. 64 + 18 80' left
24', 36' left
Twp. Road base line of Survey
Section 11
Twp. 161 N.
Rge. 51 W.
Fence Corner Sta. 70 + 75 59' left
30' ℄ Ditch to ℄ Road
Section 10
Twp. 161 N.
Rge. 51 W.
B. M. No. 4 Iron Rod 100' South Sta. 91 + 20 on west back slope of TWP. road. Elev. 794.81
C. M. P. 24" X 28', 30' left
Tie Iron Rod 32.6'
80
90
70
80
90
100
110
24", 30' Rt.
ovide Bridge,
4.0' flow depth
R/W Line 2 Rods from property
Tie Iron Rod 31.5'
C.M.P 24"X 28', 32' Rt.
Remove Provide Bridge
55 sq. ft. at 36' flow depth
Lateral
Section 2
Twp. 161 N
Rge. 51 W
1/4 Line Sta. 64+00
Section 2
Twp. 161 N.
Rge. 51 W.
Section Line Sta. 90+90.4
Section 3
Twp. 161 N.
Rge. 51 W.
N

50
60
70
80
90
100
110
787.00
787.60
787.80
788.20
788.60
789.00
789.60
Ground Surface
S = 0.0004
Hydraulic Gradient
Bottom
Slopes 0.04%
37+60.2
Acres
7
C.F.S.
Feet
"
Sq. Ft.
F/S
C.F.S.
HYDRAULIC DATA - Sta. 37+60.2 to 90+90.4
Drainage Area 4585.0 Acres
Drainage Coefficient 0.0179 "
Capacity Required 82.0 C.F.S.
Side Slopes 2:1
D 4.0 Feet
B 6.0 "
A 66.00 Sq. Ft.
r 2.34
n 0.035
S 0.0004
V 1.46 F/S
Q 82.0 C.F.S.
HYDRAULIC DATA - Sta. 90+90.4 to 140+03.2
Drainage Area 3192.0 Acres
Drainage Coefficient 0.0197
Capacity Required 63.0 C.F.S.
Side Slopes 2 : 1
D 3.6 Feet
(D was set at 4.0' minimum limit)
B 6.0 "
A 47.52 Sq. Ft.
r 2.15
n 0.035
S 0.0004
V 1.36 F/S
Q 65.0 C.F.S.

Figure 1.52-2



HYDRAULIC DATA - Sta. 90+80.4 to 140+03.2

Drainage Area	3192.0	Acres
Drainage Coefficient	0.0197	
Capacity Required	63.0	C.F.S.
Side Slopes	2 : 1	
D	3.6	Feet
(D was set at 4.0' minimum limit)		
B	6.0	"
A	47.52	Sq. Ft.
r	2.15	
n	0.035	
S	0.0004	
V	1.36	F/S.
Q	88.0	C.F.S.

Plan and profile plotted from notes on page.

SAMPLE

BRODEUR DRAIN
PEMBINA COUNTY, NORTH DAKOTA

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. BENNETT, Chief

REFERENCE: FIELD DRAWING

CARTOGRAPHIC APPROVAL:			TECHNICAL APPROVAL:	
COMPILED:	TRACED: R.H.S.	CHECKED:	DATE: 6-30-48	DRAWING NO. 5, R-7760-E

Figure 1.52-3

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

Cross Sections

a. Take cross sections at close enough intervals to provide accurate yardage computations. They should be taken at all breaks in grade.
b. Tie all cross sections to bench mark.
c. Cross sections should be extended far enough from the centerline of the ditch to secure at least 50 to 75 feet of normal ground profile.
d. Extend cross sections across old channels that parallel the proposed ditch.
e. Obtain profiles as described under Types of Surveys (profiles and cross sections) and use form of notes shown in Figure 1.28.
f. A cross section interval of 100 feet and at breaks in grade provide adequate information for yardage computations. Where land is flat this distance may be lengthened to 200 - 500 feet, but care must be exercised to insure the cross sections reflect true ground conditions, and that there are no large differences in end areas between adjacent sections.

Layout Surveys. See procedure for slope staking.

Small Farm Surface Drains. Drains which are small enough to be contained in one ownership or are used primarily for draining nuisance potholes and wet areas, can be readily surveyed and designed in the field, if necessary. The following outline with related charts and curves can be used effectively in the survey of small drains.

Design Surveys.

a. The field notebook is used to record and show the following:

(1) Profile and cross section notes on centerline of drain, with column for grade, centerline, stake line and cuts, as shown in Figure 1.53. Show grades and cuts to tenths. Bench mark levels should be shown to hundredths.
(2) Centerline shots will be taken at all stations and plusses. Cross sections will be taken at frequent enough intervals to provide an accurate measurement of yardage.
(3) The following additional information should be shown in the field book.

(a) Description and elevation of bench marks.
(b) The check to indicate closure of level circuit.
(c) Grades, side slopes and bottom widths.
(d) Party data, name of cooperator, location of drain, date.

b. Use Drain Data Sheet, Record:

(1) Name of owner and operator.
(2) Legal description and location of drains on location map.

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

Design Surveys (cont'd)

(3) Indicate on location map the direction of flow and number designation of each drain.
(4) Record hydraulic data for each drain.
(5) (a) Drainage area in acres.
(b) Capacity required in c.f.s. This quantity may be obtained from drainage curves in another part of this handbook.
(aa) Indicate which drainage curve used.
(c) Side slopes.
(d) Flow depth.
(e) Bottom width.
(f) Show grade in percent (ft. per hundred).
(aa) Where more than one grade occurs in any ditch, record the grade of critical section. Actual grades by eleva- will show in field book.
(g) Discharge "Q" in c.f.s. by actual computations or from table.
(6) Give name of person who designed and laid out job, and the dates.
(7) Indicate field book number containing survey notes, or if loose leaf, attach to drain plan sheet.
(8) Plot profile, whenever necessary to aid in design, layout and checking of the drain.
(9) Plot cross section as necessary to ascertain areas and attach to drain data sheet. These may be plotted on regular cross section paper.
(10) Calculate and record yardage.
(a) Use standard earthwork computation sheets and attach to drain data sheet.
(aa) Show stations, cuts and end areas.
(bb) Calculate area and yardage for each drain by end areas by computing (See Example figure 1.54) and referring to end area tables for level sections. When cross sections are plotted, obtain end area by direct measurement with planimeter or by calculation.
(cc) Record total yardage on drain data sheet.

Layout Surveys.

a. Use field notebook.

(1) Set stakes at 100 foot intervals and at necessary plusses and record notes in field notebook. (See slope staking procedure).
(2) Mark cuts to grade, in tenths of a foot, from ground surface, on the set, slope or centerline stakes, which ever is being used.
(3) Check into bench marks as staking progresses.

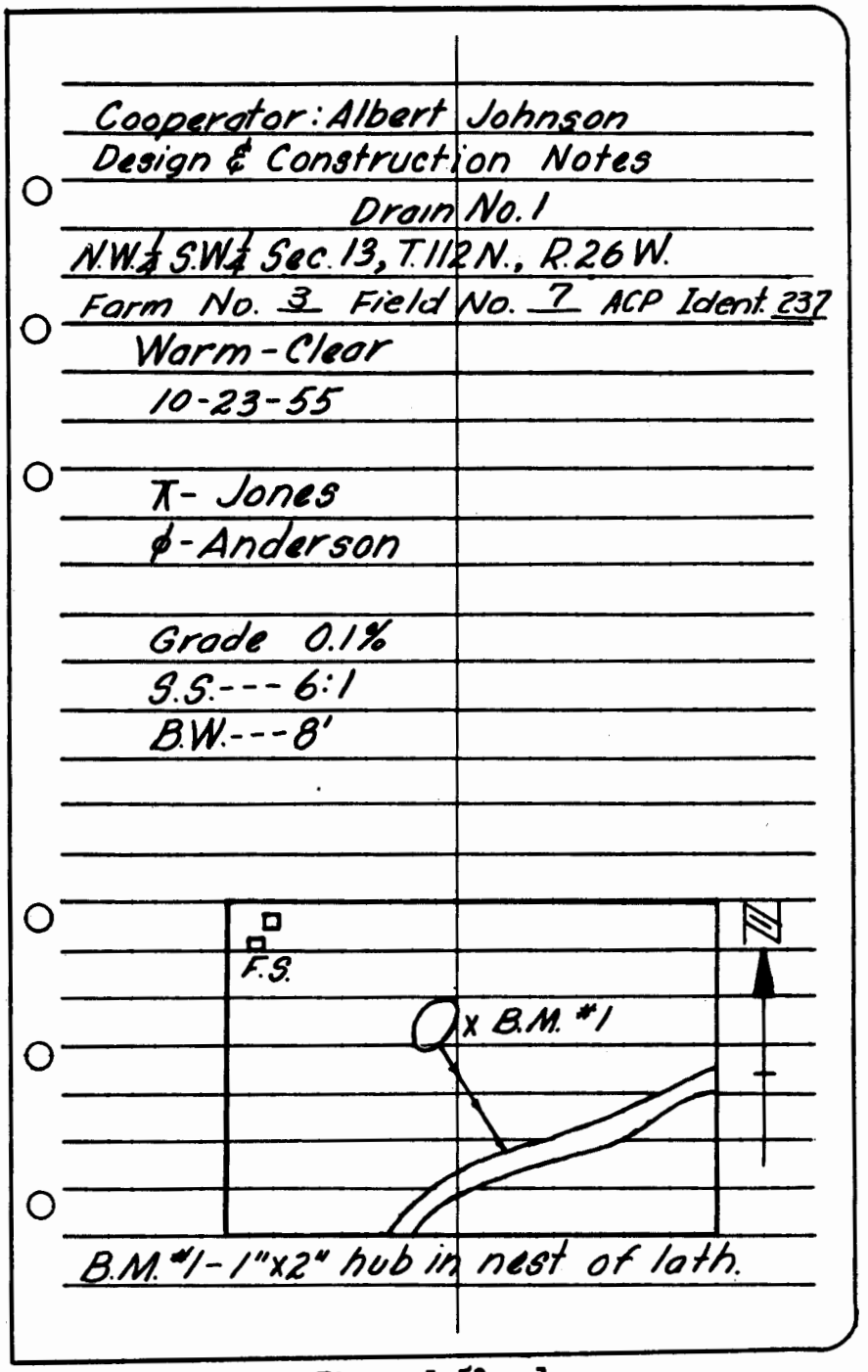

Cooperator: Albert Johnson
Design & Construction Notes
Drain No. 1
N.W.¼ S.W.¼ Sec. 13, T. 112 N., R. 26 W.
Farm No. 3 Field No. 7 ACP Ident. 237
Warm - Clear
10-23-55
T - Jones
ϕ - Anderson
Grade 0.1%
S.S. --- 6:1
B.W. --- 8'
F.S.
x B.M. #1
B.M. #1 - 1"x2" hub in nest of lath.

Figure 1.53 - 1

Sta.	B.S.	H.I.	F.S.	Grade El. or Elev.	Grade Rod ①
B.M.-1	4.92	104.92		(100.00)	
0+00				98.4	- 6.5
1+00				98.3	- 6.6
2+00				98.2	- 6.7
3+00				98.1	- 6.8
T.P.-1	3.42	103.54	4.80	(100.12)	
4+00				98.0	- 5.5
5+00				97.9	- 5.6
5+50				97.9	- 5.6
6+00				97.8	- 5.7
T.P.-2	3.93	103.05	4.42	(99.12)	
B.M.-1			3.05	(100.00)	
	12.27		12.27	no error	
	Cross Section Check Out				
1+00					
3+00					
5+00					
5+50					

DRAIN No. 1 ①

Albert Johnson

Slope Stakes

Side Slopes 6:1 Bottom 6.0'-0.10 grade

1"x2" Hub in nest of lath 100' N.E. of 0+00

									Offset Stake line 25' Rt
		6.0		6.0		6.0			6.1
		C=0.5-7.0'		C=0.5		C=0.5-7.0'			C=0.4
		6.1		6.1		5.2			5.2
		C=0.5-7.0'		C=0.5		C=1.4-12.4'			C=1.4
4.1	4.4	4.5		4.0	4.5	4.5	3.2		3.0
C=2.6-19.6'	10	6		C=2.7	6	9	C=3525.0		C=3.7
		5.1		5.1		5.2			5.2
		C=1.7-14.2'		C=1.7		C=1.6-13.6			C=1.6
		4.7		5.0		4.9			3.8
		C=0.8-8.8'		C=0.5		C=0.6-7.6			C=1.7
4.3	4.3	4.7	5.1			5.0			4.1
C=1.3-11.8'	9	6	C=0.5			C=0.6-7.6			C=1.5
		5.4		3.6		3.7			3.9
		C=0.2-5.2'		C=2.0		C=1.9-15.4			C=1.7
		5.7		5.7		5.7			4.4
		C=0.0-4.0'		C=0		C=0.0-4.0'			C=1.3

checked ok - Peter Nelson

Top Width Staked	Top Width Chk'd	Bottom Width Stk'd	Bottom Width Chk'd	Side Slope	
19.4'	19.4'	8'	8.0'	6.1	C=1.4
27.8'	27.8'	8'	8.0'	6.1	C=1.4
19.4'	19.4'	8'	8.0'	6.1	C=1.5
20.6'	20.6'	8'	8.0'	6.1	C=1.8

Figure 1.53 - 2

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

PROCEDURE FOR DETERMINING END AREAS BY CALCULATION; WHEN SLOPE STAKES ARE SET AND SLOPE IS UNIFORM FROM ℄ TO SLOPE STAKES, ON DRAINAGE DITCHES

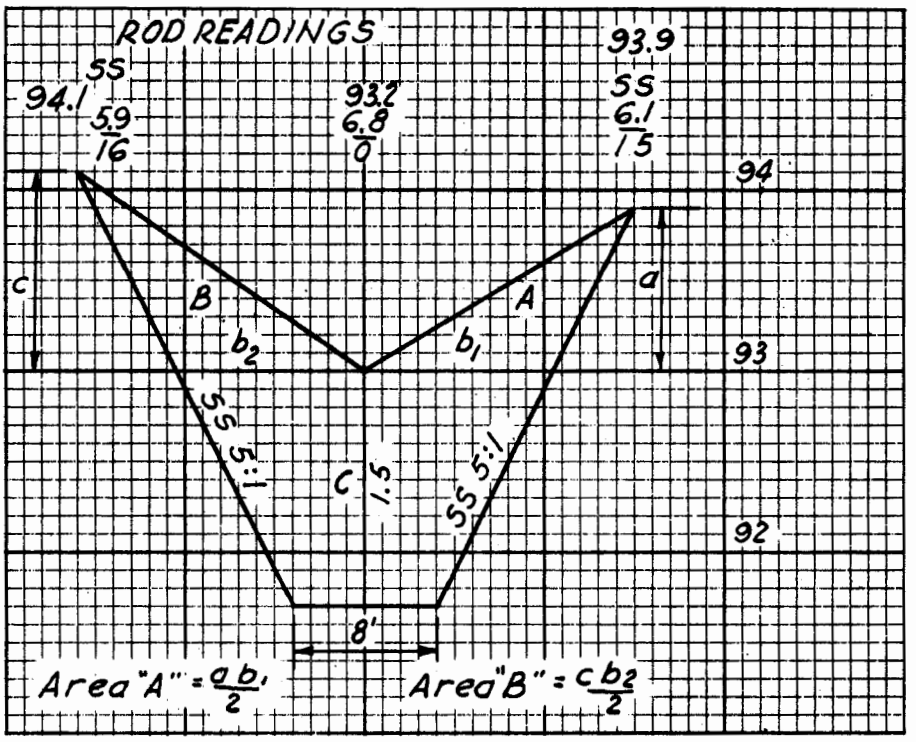


Figure 1.54

$b_1 = b_2 = (℄ \text{ cut}) \times \text{side slope} + \frac{\text{Bottom width}}{2}$

Area "A" + "B" = $(a + c)\frac{b_1}{2}$

a = (℄ Rod) minus (slope stake rod)
c = (℄ Rod) minus (slope stake rod)

Area "C" = sq. feet for ℄ cut from end area table.

Total Area = "A" + "B" + "C"

Example as shown

$b_1 = (5 \times 1.5) + 4 = 11.5$
$a = 6.8 - 6.1 = 0.7$ $\quad c = 6.8 - 5.9 = 0.9$

Area "A" + "B" = $(0.7 + 0.9)\frac{11.5}{2} = \frac{1.6 \times 11.5}{2} = 0.8 \times 11.5 = 9.2$

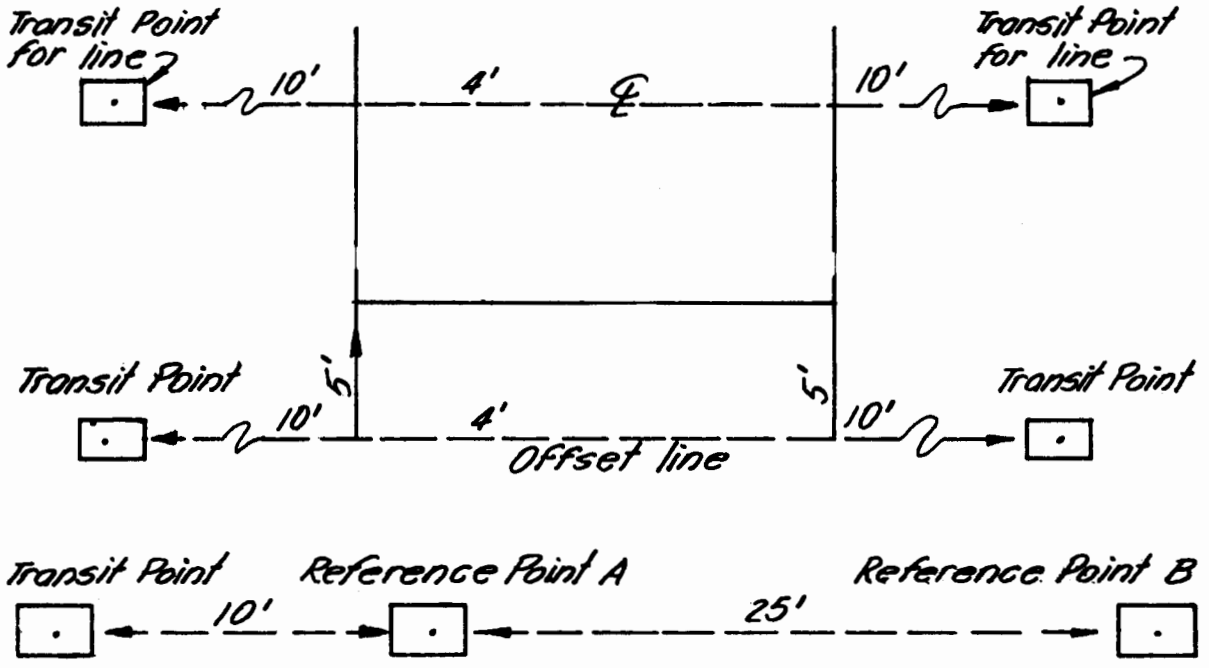
Note: Areas "A" and "B" are added algebraically to Area "C". (If slope stake(s) is lower than ℄ stake, it is subtracted.)
"C" = 23 Total area = 32.2 or 32 sq. ft.

12. EXAMPLES OF SURVEYS FOR CONSERVATION STRUCTURES (CONT'D)

Layout Surveys for Structures. In the layout of structures, stakes are set to indicate line and grade. Alignment stakes may be set along the centerline (℄) of the structure or along one side of it to establish a base line. The constructor can then readily locate the structure from this base line. The end stakes should be far enough away from the structure so that they will not get knocked out. In this way, the base line can be easily relocated at any time. A line parallel to ℄ is often used as a reference from which the ℄ can be easily re-established. When the structure is large and/or complex, stakes are set at corners or other specific points to locate the exact position and orientation of the structure. These stakes may be "referenced" by driving other stakes a known distance and direction from them. Thus they can be easily relocated when they are destroyed during construction operations. See Figure 1.55.

Grade stakes or blue tops are set at a specified elevation and close enough to the structure that the constructor can use them in setting the structure at the correct elevation. Grade stakes should be referenced by means of a bench mark located close by but in a well protected place where it will not be destroyed.

EXAMPLE OF SETTING ALIGNMENT STAKES AND REFERENCE POINTS.



When transit point becomes destroyed it may be accurately relocated by resetting it 10' from RPA and on line with RP'S A and B.

Figure 1.55

12. EXAMPLES OF SURVEY FOR CONSERVATION STRUCTURES (CONT'D)

SETTING GRADE STAKES FOR STRUCTURES

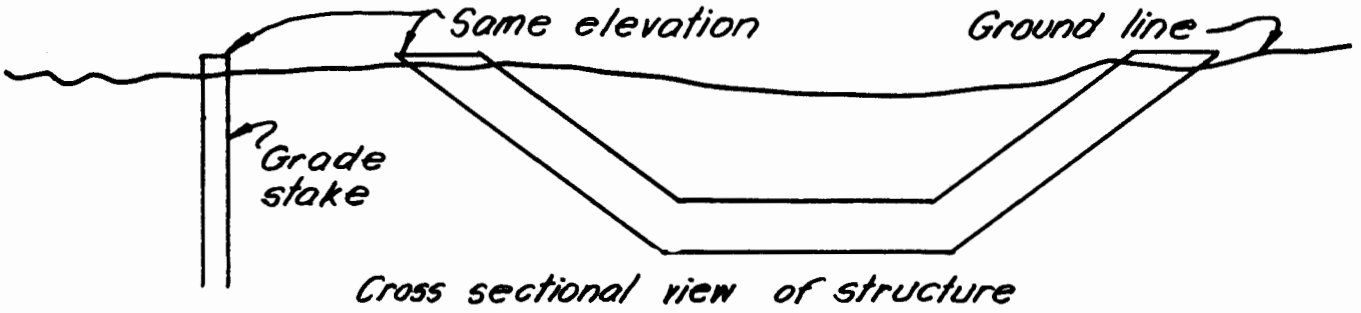


Figure 1.56

Grade stakes may be set on grade, below grade, or above grade. "Blue tops" indicate grade, "red tops" indicate an elevation other than grade.

Transit points are driven nearly flush with the ground. A guard stake identifying the point is driven to mark the point.

The location and elevation of all but temporary or intermediate stakes should be clearly and completely described by notes and sketches in the field notebook.

In staking out the drains or pipe lines the center line is defined on the surface of the ground and stakes are set at intervals of 25 to 50 feet on this centerline.

Profile levels are then run along the centerline at each stake and the elevations plotted on profile paper. The desired grade line of the tile or pipe is then plotted on the same profile. The grade line is the flow line or the invert of the tile or pipe. (The lowest point on the inside of the tile or pipe). When the surface profile and grade line has been plotted, the cut of each station may be obtained by subtracting the grade elevation from the ground surface elevation. These cuts are then transferred to stakes set along side the proposed trench to aid in excavation.

When the trench has been dug to grade the centerline is rerun over the trench and planks and stakes are set as shown in Figure 1.57.

The centerline can be defined easily by nailing a stake with one edge on centerline location. A nail is driven at some full number of feet above the flow line into this stake. (The top of the plank may also be used.) A string line may then be stretched between stations and the tile or pipe set to grade by use of a grade rod or pole marked with even feet throughout its length. A right angle bracket is usually attached rigidly to the bottom of the pole and extends into and rests on the invert of the pipe.

12. EXAMPLES OF SURVEY FOR CONSERVATION STRUCTURES (CONT'D)

Layout Surveys for Structures (cont'd)

Some care is necessary to keep the pole vertical when measuring and to keep the string taut.

BATTER BOARDS FOR TILE

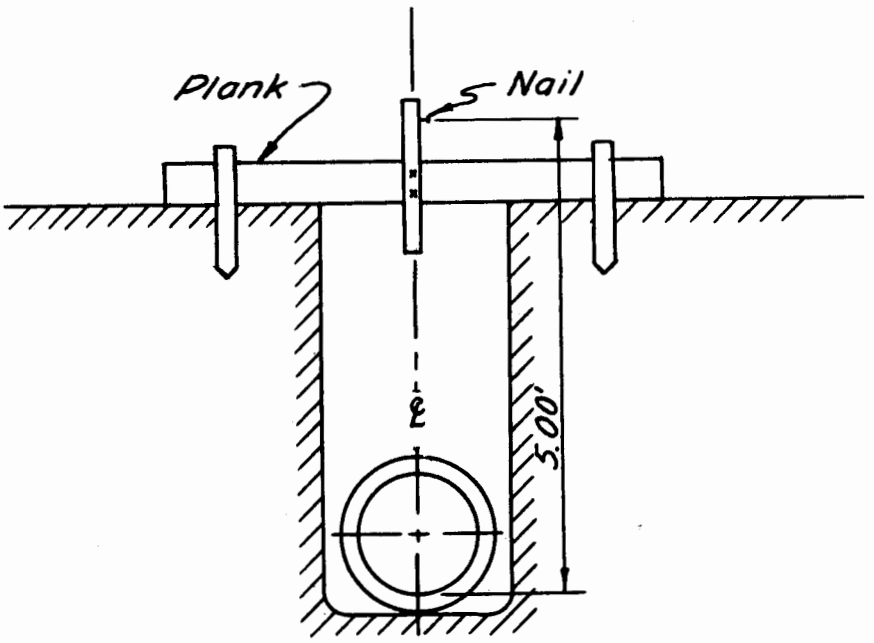


Figure 1.57

13. LAND SURVEYS (GENERAL)

The survey of public lands does not ordinarily concern the Soil Conservation Technicians, but the system of subdivision used in most states should be understood.

Scheme of Subdivision. The primary unit is the township bounded by meridional and latitudinal lines. The township is approximately 6 miles square. Due to convergence of the meridians (see Figures 1.58 and 1.59), it is quite impossible to have a perfectly square township.

The township is divided into 36 secondary units called sections and as nearly 1 (one) mile square as possible. See Figure 1.60.

Townships and sections are located with respect to two principal axis passing through an origin called an initial point. The lines which form the axis are a true meridian, called the principal meridian, and a true parallel of latitude, called the base line.

Secondary axis are established at intervals of 24 miles north or south of the base line and at 24 miles east or west of the principal meridian.

13. LAND SURVEYS (GENERAL) (CONT'D)

Scheme of Subdivision (cont'd)
This divides the area into quadrangles bounded by true meridians 24 miles long and by true parallels. The south boundary of each quadrangle is 24 miles long and the north boundary is 24 miles long less the convergence of the meridians in that distance.

A row of townships extending north and south is called a range and a row extending east and west is called a tier. Tiers (or townships) are counted north or south of the base line and ranges are counted east or west of the principal meridian. A township five tiers south of the base line and three ranges east of the principal meridian would be designated as T-5 south R-3 east.

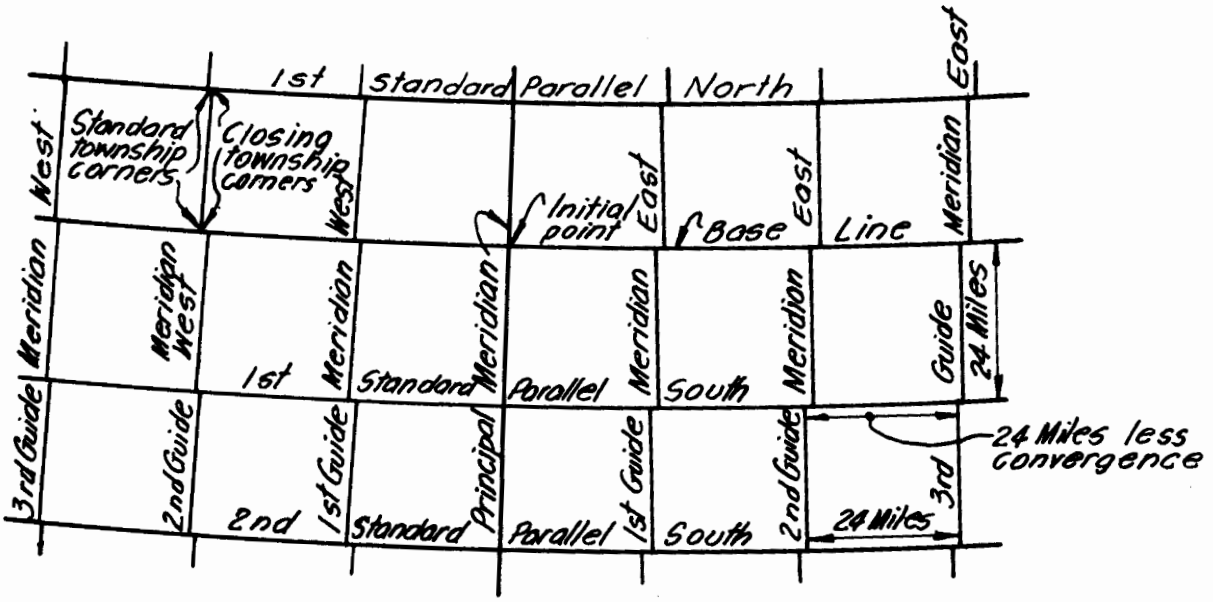
The division of a township into sections is done by establishing lines at intervals of 1 mile parallel with the east boundary of the township and joining the section corners established on these lines at 1 mile intervals with straight latitudinal lines. Thus the township is divided into 36 sections numbered as shown in Figure 1.60.

The subdivision of sections into quarter sections and quarter-quarter sections is too lengthy to be discussed here fully, but a brief explanation is given:

The establishment of quarter lines is accomplished by first identifying the section corners and quarter section corners. Straight lines are then run between opposite quarter section corners previously established on the boundaries of the section (see Figure 1.61). The point of intersection of these two lines is the common corner of the four quarter sections and the legal center of the section. The subdivision of a quarter section into quarter-quarter sections is accomplished by finding the point midway between section and exterior quarter section corners and between the exterior quarter section corners and the center of the section. Straight lines are then run between opposite corresponding quarter-quarter corners. See Figure 1.61.

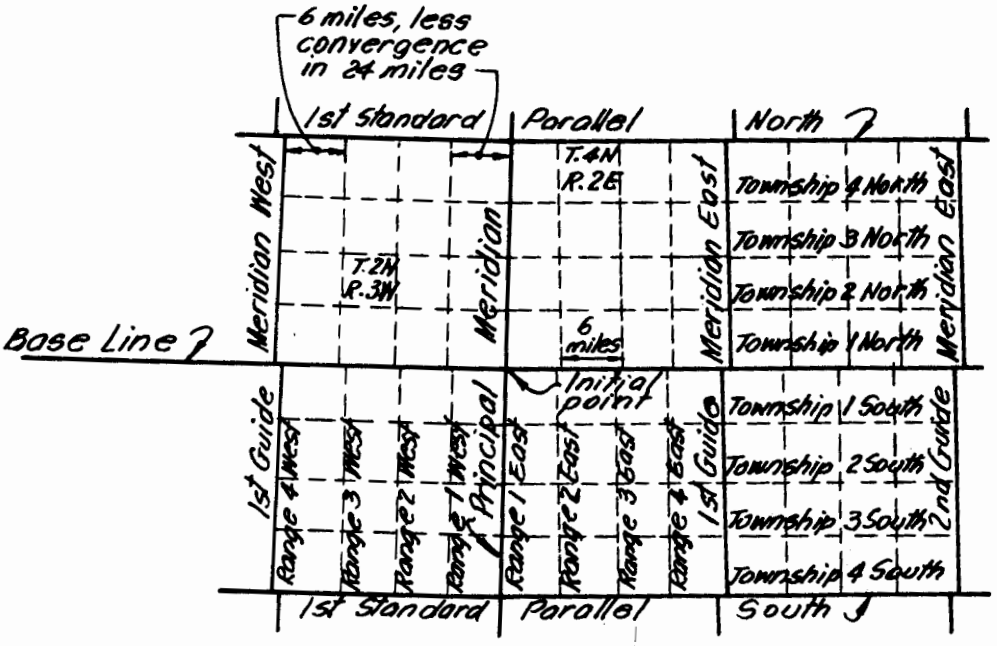
If the section falls on the north and west boundary of a regular township the excess or deficiency in measurement is thrown into the half mile next to the range or township line. See Figure 1.60.

It should be understood that section lines are not necessarily straight; that is, there may be a deflection at a quarter section corner. In many cases this deflection is small but in some it may be quite appreciable. Where a drain or other project is being constructed on or adjacent to a property line this should be kept in mind.



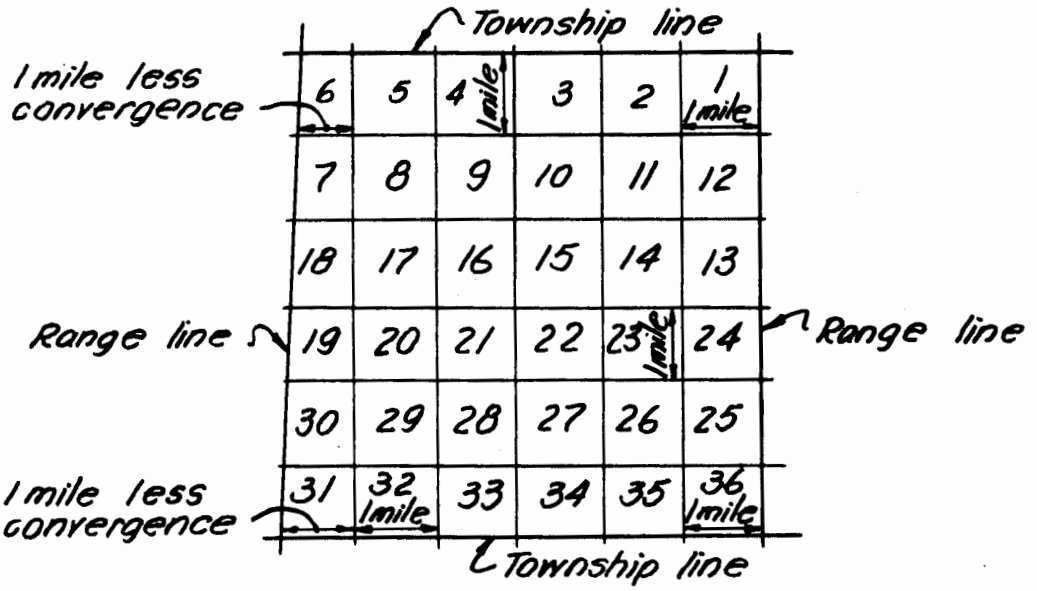
GUIDE MERIDIANS AND STANDARD PARALLELS

Figure 1.58

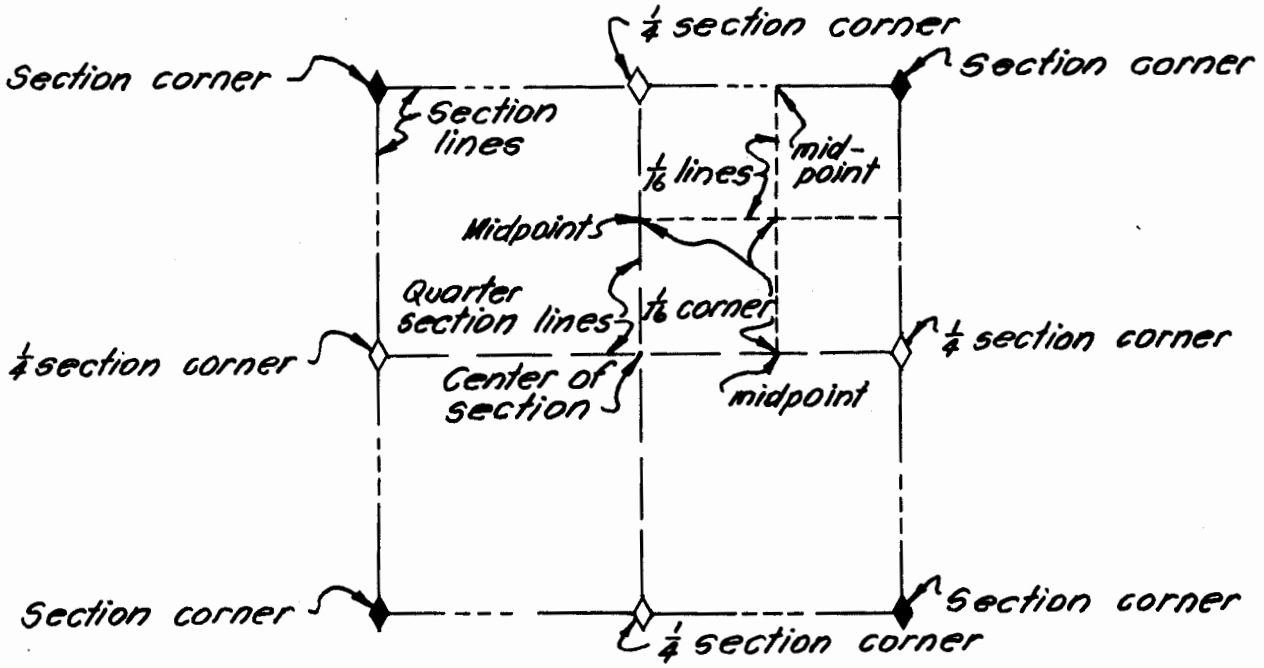


TOWNSHIP AND RANGE LINES

Figure 1.59



NUMBERING OF SECTIONS
Figure 1.60



SUBDIVISION OF REGULAR SECTION
Figure 1.61

GPO 853874

CONTENTS

PART 2

DATA SHEETS

Subject	Page
1. General	2-1
Purpose	2-1
Orderly Procedure	2-1
2. Record Keeping	2-3
3. Drafting	2-3
General	2-3
Lettering	2-3
Title Block	2-3
Use of Pencil	2-4
Symbols	2-4
Scales and North Arrow	2-4
Legal Description	2-4
Bench Marks	2-4
Standard Size Sheets	2-5

LIST OF FIGURES

PART 2

DATA SHEETS

Fig. No.	Title	Page
2.1	Standard Legend for Soil Boring Logs	2-6
2.2	Soil and Foundation Investigations Log of Borings	2-7
2.3	Log Sheet for Earth Borings	2-8
2.4	Soil Sample List, Soil and Foundation Investigations	2-9
2.5	Land Use Map Legend	2-10
2.6	Structural Design: Drawing Sizes and Title Blocks for Engineering Division - Design Section Drawings	2-11
2.7	" " " " " "	2-12
2.8	Earthwork Computation Sheet	2-13
2.9	Type of Lettering	2-14

PART 2

DATA SHEETS

1. GENERAL

Purpose

Data sheets in soil conservation work provide:

(1) an orderly and analytical approach and solution to any problem in design of structures and works,

(2) the details of design for the construction of these works and measures,

(3) a permanent record for future reference.

Data sheets are drawings or sets of drawings which show engineering field survey data of the present and future conditions, hydrologic information for design, and hydraulic data for computations and design. The final data sheets and plans used for construction purposes are supported by a set of specifications showing many details other than those shown on the plans. Detailed cost estimates of materials must be developed and may be summarized on the plans.

Orderly Procedure

The placement of information on data sheets must follow an orderly procedure. This will insure complete coverage of all needed data and in the proper sequence.

There may be many parts to a data sheet, such as the title block, location map, drainage area map, soil boring log, materials estimate, cost estimate, or detailed sketches. Each of the appropriate parts must be completed and all data included.

Most data sheets have a title block which must be filled out to properly identify the work. The project name, the organization doing the design work, and the names of the designer and checker must be noted. The dates on which the design and checking were completed must also be shown. Each sheet should be numbered where there are more than a single sheet, such as sheet 1 of 3, etc. The title block should show where additional basic information can be found and a reference to the engineering field book number and page.

A small-scale location map will help locate the area of work. Include a north arrow, the legal description of the project, and identify or locate the survey bench marks. The elevation of the bench mark may be an assumed elevation or it may be referenced to sea level.

1. GENERAL (CONT'D)

Orderly Procedure (cont'd)

A drainage area or watershed sketch may be necessary. The sketch should show the location of the structure in the drainage area, the area in acres, and other physical features, such as buildings, roads, power lines, telephone lines, gas lines, etc.

Plot the engineering survey information by profiles or cross sections to show field conditions properly. Plotted profiles should describe the ground surface elevations along the line of the survey as well as any other control shots that may affect the design. Survey profiles may be plotted on either profile paper or plan and profile paper.

To select the profile scale and starting points for plotting profiles, first determine from the field notes the total length of the profile to be plotted and the total difference in elevation. Then select the horizontal scale and the horizontal starting point so the entire profile will be well spaced on the profile paper, taking into account any other material to be drawn on the sheet. Select the vertical scale and a starting point so the entire profile will be well spaced on the paper vertically. Remember that other material may need to be shown on the profile paper.

Where the bottom and banks of a ditch are plotted on the same profile sheet, the banks are named right and left when looking in the direction of the stationing. Be sure to identify all profile information by horizontal stations and vertical elevations.

All cross sections should be placed on cross section paper (10 x 10 to the inch). They should be plotted as viewed looking downstream. Show the center line or distances from the offset line. Elevations should be shown from an assumed elevation or from mean sea level (M.S.L.). The profile station at which each cross section survey was taken should be indicated directly under each plotted cross section.

Samples of soil borings are used to analyze foundation conditions of soils for contemplated structures or ponds, or to analyze the drainage properties of soils for contemplated open ditches and tile drain jobs. They are also used to determine the presence of quick sand, rocks and other undesirable sub-surface conditions in connection with open ditch and tile drainage. On all engineering design sheets, boring logs should be plotted on the data sheet profiles or on the cross sections at the location they were taken whenever space is available. When space is not available, identify the locations on the cross sections or profiles and plot the soil logs, with proper identification, to one side. In either case the logs should be plotted on the same datum used for the profiles or cross sections.

The standard legend for soil boring logs is given in Figure 2.1

Data sheets for recording information from drilling are shown by Figure 2.2 and Figure 2.3. Figure 2.4 is a data sheet used for sending soils samples to the Soil Mechanics Testing Laboratory.

2. RECORD KEEPING

All of the sheets used for information on the design, layout, and checking of construction of various conservation practices are data sheets. Data sheets are usually self-explanatory for practices such as contour farming, field diversion, terracing, erosion control dam, etc. Blank spaces are usually provided for information on hydrologic, hydraulic, layout, or construction features relating to the practice.

3. DRAFTING

General

Skilled drafting technique is not expected of field personnel preparing engineering plan sheets and other drawings. However, field personnel whose duties require the preparation of engineering data sheets or other drawings are expected to do such work in a legible, neat, orderly and understandable manner. The appearance of the drawings will affect the degree of confidence with which they are received by persons outside the Service.

Lettering

Information on how to improve your lettering can be found in any textbook on surveying. All lettering and numbers within the body of engineering data sheets should be 3/20 inch high for capitals and 2/20 inch high for lower case letters. On the profile paper, this is equivalent to three letters. Titles used outside the title block should be all capitals 1/4 inch high (five of the fine lines on the profile paper). Do not use lettering any smaller than specified above or it will be difficult to read if the drawings are reduced in size by photostatic reproduction. (See sample sheet on type of lettering, Figure 2.9.)

Title Block

Every engineering data sheet or drawing must have a title block. The title block is to give the subject of the drawing. A standard title block has been established for use on engineering plans and shown by Figure 2.6. It will be used to identify engineering plans prepared in the state. It is printed as a letterpress stickup so it can be easily attached to plan sheets. The letterpress stickup may be used on plan and profile and cross section paper without any appreciable loss of clarity. A copy is attached to Washington Engineering Letter No. 5. It measures 5½ inches wide by 3½ inches high and is primarily adapted to Service standard "E" size sheets. For "L" and "N" size sheets, the standard type "A" title block shown on drawing ES-16, Section 6, Structural Design, Engineering Handbook, may be used, adding spaces for any approvals that may be required. When letterpress stickups are not used, the standard title block shall be drafted on the drawing. Under conditions where plans are submitted to State agencies for approval, the title block should be in basic accord with the requirements of the State. Normally our standard title block should be used, making whatever additions are needed to meet the State agencies' requirements. If our standard title block cannot be adapted, its basic elements

3. DRAFTING (CONT'D)

Title Block (cont'd)

should be incorporated in the title block to be used. The letterpress stickup title block is printed and stocked for distribution at the Cartographic Unit and may be requisitioned.

Use of Pencil

Nearly all field drawings will be done in pencil. With reasonable care a very creditable drawing can be turned out in pencil. If the proper weight line is used, good photostatic reproductions or ozalid prints can be made. The use of good pencil drawings may eliminate ink tracings. Tracing paper equivalent to Posts #173 should be used.

Symbols

Map symbols used are to be in conformance with those shown in Figure 2.5; soil boring log symbols, Figure 2.1; and earth boring symbols, Figure 2.3. A legend explaining the symbols used must be put on data sheets or engineering drawings.

Scales and North Arrow

Maps on engineering data sheets should always have bar scales. This is necessary because the original scale of engineering data sheets and drawings is very often reduced or enlarged when reproduced. A map scale given, as one inch equals 100 feet, would have no meaning after the drawing has been reduced to half size by photostat. A bar scale, however, is reduced the same as the rest of the drawing. It is unnecessary to include bar scales on profiles, cross sections and boring logs because stationing and elevations are shown in each case.

North arrows should be shown near each watershed map, location map, and topographic map. It is general practice among field engineers to use their own style north arrow and this is acceptable so long as it is not too elaborate.

Legal Description

The legal description of the section in which the main engineering work is located must be shown in the space provided in the title block. In addition, each watershed map, location map and topographic map should be tied into a properly identified section or quarter section corner.

Bench Marks

The elevation, location and identification of all bench marks must be shown on all plans and maps.

3. DRAFTING (CONT'D)

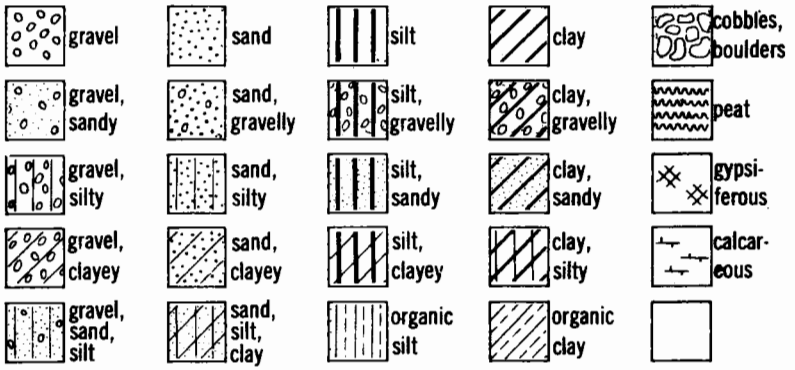
Standard Size Sheets

Standard size drafting sheets (21" x 30") are established for use throughout the Service for engineering drawings and are designated as "E" size sheets. See Figure 2.7. The sizes of 8 inches by 10½ inches ("L" size sheet) and 10½ inches by 15 inches ("N" size sheet) can be used, if desired, for simple jobs encountered in normal farm planning operations and jobs where schematic plans are used to supply information to state agencies and others. The standard size sheet "E" will have a 1½ inch border on the left side and a ½ inch border on all other sides. On size "L" and "N" sheets the left-hand border must be 1¼ inch and the other borders 3/16 inch. Commercially available tracing paper printed in cross section, profile, and plan and profile, manufactured in rolls, is engraved to a width of 20 inches. This class of paper can be readily adapted to the 21 inch width and cut to the required length. Standard BPR cross section and plan and profile sheets can be blocked out and trimmed to size.

STANDARD LEGEND FOR SOIL BORINGS LOGS

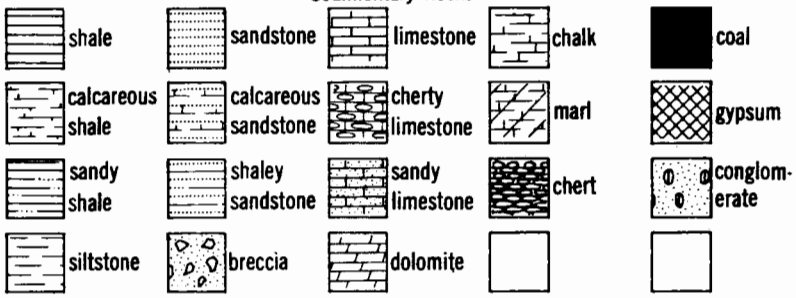
GEOLOGIC SYMBOLS

UNCONSOLIDATED MATERIAL

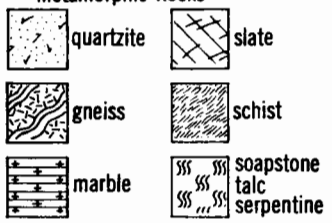


CONSOLIDATED MATERIAL

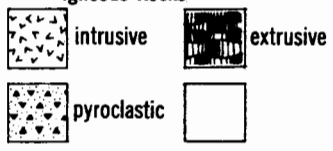
Sedimentary Rocks



Metamorphic Rocks



Igneous Rocks



Undifferentiated

GEOLOGIC ABBREVIATIONS

aq	aquifer	fri	friable
cav.	cavities	lam	laminated
℄	centerline	mas	massive
con	concretions	TD	total depth
US	undisturbed samples	v.	very
DS	disturbed samples	w/	with
dip	dipping	wea	weathered
frac	fractured	WL	(date) groundwater level on a specified date

TEST HOLE NUMBERING SYSTEM

Centerline of dam	1 - 99
Borrow area	101 - 199
Emergency spillway	201 - 299
Centerline of outlet structure	301 - 399
Stream channel	401 - 499
Relief wells	501 - 599
Other	601 - 699

OTHER SYMBOLS

- pit or trench
- hole logged only
- hole sampled

UNIFIED SOIL CLASSIFICATION SYMBOLS

- **GW** Well graded gravels; gravel-sand mixtures
- **GP** Poorly graded gravels
- **GM** Silty gravels; gravel-sand-silt mixtures
- **GC** Clayey gravels; gravel-sand-clay mixtures
- **SW** Well graded sands; sand-gravel mixtures
- **SP** Poorly graded sands
- **SM** Silty sand
- **SC** Clayey sands; sand-clay mixtures
- **ML** Silts; silty, V. fine sands; sandy or clayey silts
- **CL** Clays of low liquid limit and medium plasticity; silty, sandy or gravelly clays and clayey silts
- **CH** Inorganic clays of high liquid limit and high plasticity; fat clays and silty clays
- **MH** Elastic silts; micaceous or diatomaceous silts
- **OL** Organic silts and organic silty clays of low liquid limit and low plasticity
- **OH** Organic clays or silts of high liquid limit and medium to high plasticity

Figure 2.1

Form SCS-533
MAY 55

U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SOIL AND FOUNDATION INVESTIGATIONS
LOG OF BORINGS

Location _____ Owner _____ State _____ Area _____

Watershed _____ Sub-watershed _____ Site No. _____

Logged by _____ Date _____ 19__ Project: WP1 ____ WP2 ____ FP ____ Pub. 46 _____

Sampling Equipment _____ Location of borings _____

Hole No.	Location & Surface Elev.	Hole Depth From Ft.	Hole Depth To Ft.	Description of Material (note depth at which water occurs)	Sample No.	Sample Type *	Depth From Ft.	Depth To Ft.

Sheet ____ of ____ Sheets

Figure 2.2

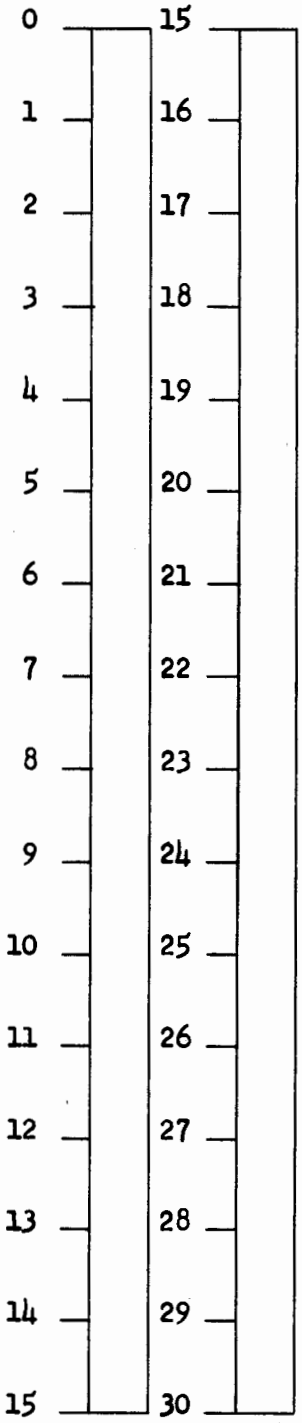
* Disturbed - undisturbed - rock core. 1 Copy to E and WP unit. Distribute other copies as directed by State Conservationist.

SD-47
7/55

UNITED STATES DEPARTMENT OF AGRICULTURE
Soil Conservation Service
LOG SHEET FOR EARTH BORINGS

Area Number _____ Hole Number _____
Work Unit _____ Date _____
Project or Cooperator _____ Technician _____
Drilling Location _____

LOG



LEGENDS
Sediment Type

A - Clay - gumbo

B - Silt

C - Sand, very fine

D - Sand, medium

E - Sand, coarse

F - Gravel, unassorted

H - Gravel, assorted

K - Bedrock (state kind)

L - Clay Loam

P - Silt Loam

T - Sandy Loam

W - Quicksand

Symbol	Degree of Permeability	Percolation in Inches Per Hour
1	Very slow	Less than .05
2	Slow	0.05 to 0.20
3	Moderately slow	0.20 to 0.80
4	Moderate	0.80 to 2.50
5	Moderately rapid	2.50 to 5.00
6	Rapid	5.00 to 10.00
7	Very rapid	More than 10.00

NOTE: Show number designating permeability for each soil or sediment type.

REMARKS: _____

Figure 2.3

Form SCS-534
MAY 55

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

SOIL SAMPLE LIST
SOIL AND FOUNDATION INVESTIGATIONS

Location_____ Owner_____

Watershed_____ Sub-watershed_____ Site No._____

Submitted by_____ Date_____ 19____

Sent by_____ Government B/L No._____
(carrier)

Lab. No.	Field Sample No.	Sample Description		Depth		Type of Sample	
		Location	Grid or Station	From	To	Undist.	Dist.

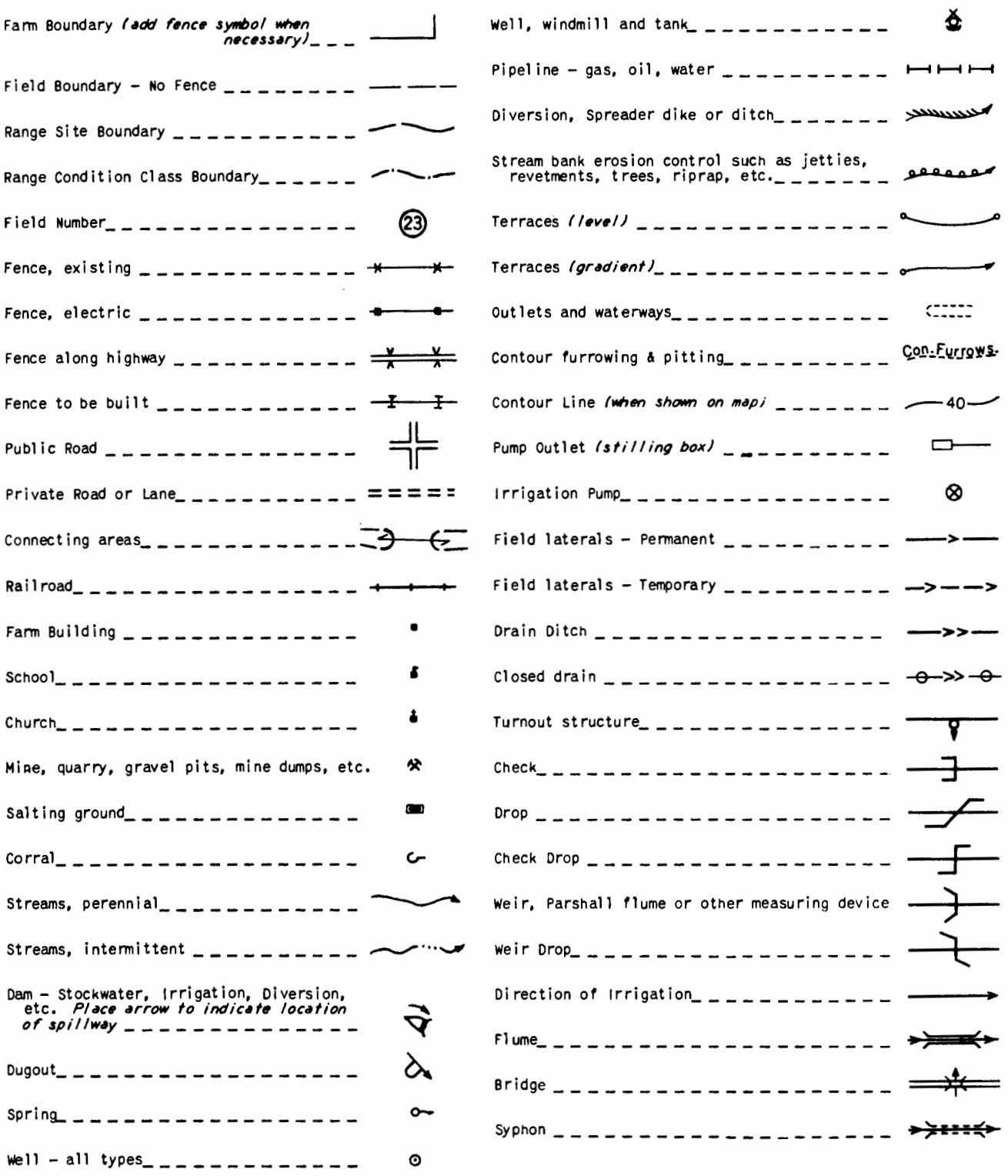
Original to Soils Laboratory
Copy to E and WP Unit
Distribute other copies as directed by State Conservationist

Figure 2.4

Sheet____ of____ Sheets

Bozeman, Mont.

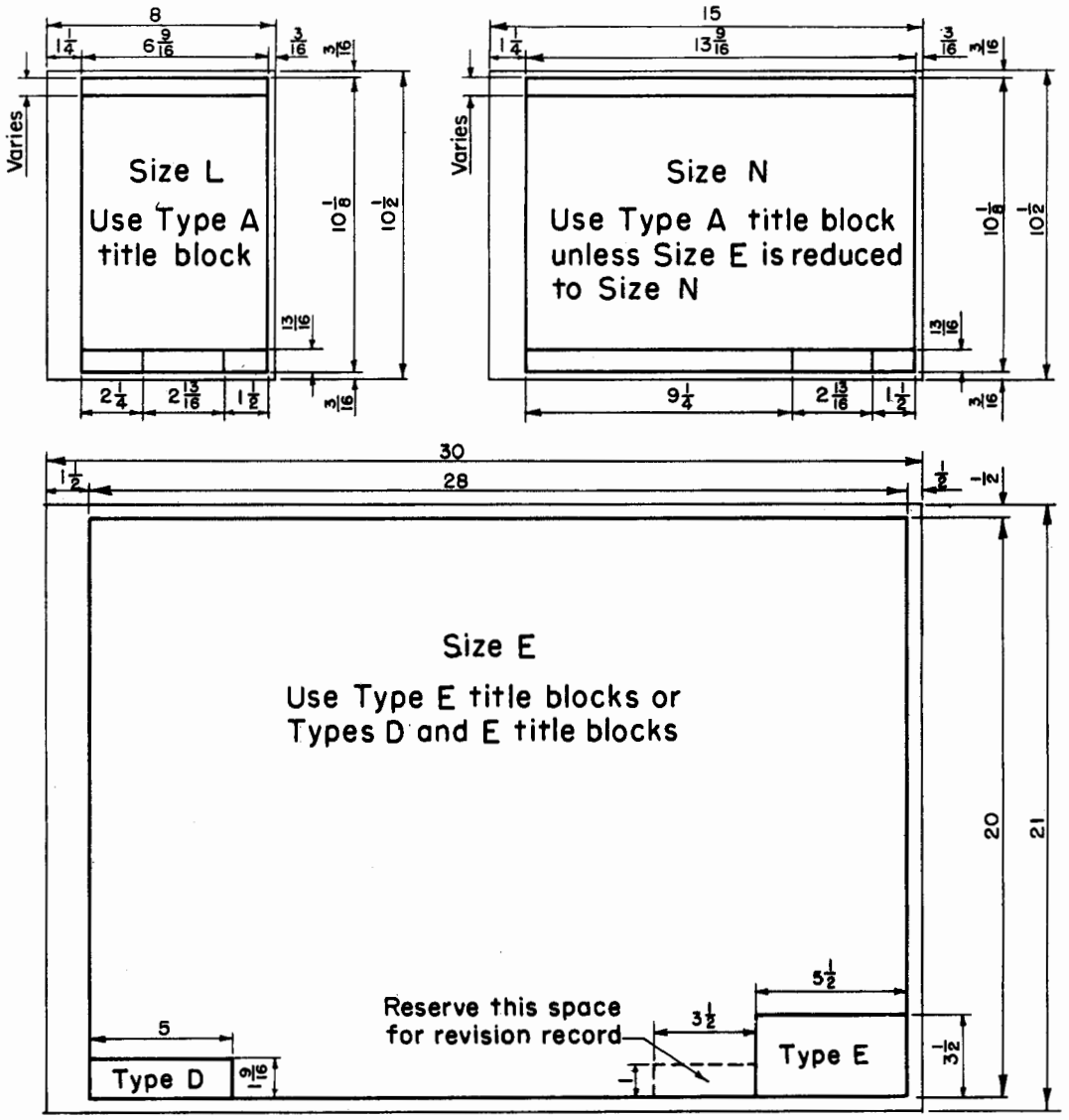
LAND USE MAP LEGEND



UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Figure 2.5

STRUCTURAL DESIGN: DRAWING SIZES AND TITLE BLOCKS FOR ENGINEERING DIVISION—DESIGN SECTION DRAWINGS


Size L
Use Type A title block
Size N
Use Type A title block unless Size E is reduced to Size N
Size E
Use Type E title blocks or Types D and E title blocks
Reserve this space for revision record
Type D
Type E
Varies

NOTES: The following notes apply to all drawings prepared by or for the Engineering Division--Design Section.

1. In their final form, all drawings will be one of the above sizes and will have border and trim lines.
2. All size E drawings will be prepared to take a linear reduction of 1 to 0.5.
3. Type A Title Block will be used on size L and N drawings prepared for inclusion in the handbook. This title block consists of two parts, one at the top of the sheet and the other at the bottom.
4. Type E Title Block will be used on all size E drawings.
5. Type E and D Title Blocks will be used on all standard detailed structure drawings that are to be incorporated into a set of construction plans. Type E will be placed in the lower right-hand corner of the drawing and Type D in the lower left-hand corner. On these drawings the Type D Title Block will be filled out by the Engineering Division--Dasign Section at the time the original drawing is prepared. The Type E Title Block will be completed by the Engineering and Watershed Planning Unit using the standard.
6. A space 3 1/2 x 1 inch, as shown above, on E size drawing, will be left vacant (without border lines) for a record of drawing revisions.
7. All typewritten material placed on drawings size L and N except titles and notes will not have a linear reduction greater than 1 to 0.75 in the final form.

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES- 16 SHEET 1 OF 2 DATE 4-7-50

Figure 2.6

STRUCTURAL DESIGN: DRAWING SIZES AND TITLE BLOCKS FOR ENGINEERING DIVISION-DESIGN SECTION DRAWINGS

Type A

The title block used at the top and bottom of this sheet is type A

ENGINEERING DIVISION - DESIGN SECTION	
ENGINEERING APPROVAL	CARTOGRAPHIC APPROVAL
DESIGNED BY	DRAWN BY
CHECKED BY	STANDARD DWG. NO.
DATE :	SHEET OF

9/16

5

Type D

U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE		
Date Designed	Approved by Title	
Drawn	Title	
Traced	Sheet No of	Drawing No.
Checked		

3 1/2

5 1/2

Type E

REFERENCE	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-16 SHEET 2 OF 2 DATE 4-7-50

Figure 2.7

Form SCS-529
MAY 55

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

EARTHWORK COMPUTATION SHEET

Location _____ Owner _____

Watershed _____ Sub-watershed _____ Site No. _____

Contractor _____ Computed by _____ Date _____ 19___

Item _____ Checked by _____ Date _____ 19___

Contract No. _____ Estimate _____ C.Y. Actual _____ C.Y.

Station	End Area Sq. In.	End Area Sq. Ft.	Sum of End Areas Sq. Ft.	Distance in Feet	Section Products Cu. Ft.	Volume Cu.Yd.	Remarks

Figure 2.8

Sheet of sheets

Figure 2.9

CONTENTS

PART 3

ESTIMATING RATE AND VOLUME OF RUNOFF

Subject	Page
1. General	3-1
2. Peak Rate	
Definition	3-1
Limitations	3-1
Data Required	3-1
Step Procedure for Computing Peak Rate Discharge	3-4
Hydrograph for Design Storm	3-4
Example of Procedure for Peak Rate Discharge	3-6
Sample Summary Sheet	3-7
3. Annual Surface Yield	
Definition	3-19
Limitations	3-19
Data Required	3-19
Example of Procedure	3-20

LIST OF FIGURES

PART 3

ESTIMATING RATE AND VOLUME OF RUNOFF

Figure No.	Title	Page
3.1	Expected Storm Rainfall in Inches - Six Hour Storm	3-8
3.2	Soil Cover Complex Numbers	3-9 & 10
3.3	Hydrologic Soil Groups	3-11 & 12
3.4	Velocities in Selected Channels	3-13 & 14
3.5	Precipitation Versus Runoff	3-15 & 16
3.6	Rainfall Intensity Distribution Zones	3-17
3.7	Unit Peak Discharge Versus Time of Concentration	3-18
3.8	(Not Included)	
3.9	(Not Included)	
3.10	Total Annual Yield of Surface Runoff	3-21

PART 3

ESTIMATING RATE AND VOLUME OF RUNOFF

1. GENERAL

The procedures herein are primarily for estimating surface runoff. They are not applicable to mountainous areas where both, maximum rate and volume of surface runoff result almost entirely from spring melting of the winter's "snow pack". The procedures are applicable, however, in inter-mountain (below elevation 6000) and plains areas of snow melt runoff based on the assumption that the maximum peak rate of runoff results entirely from summer rain storms.

The procedures are applicable for estimating surface runoff from all storms up to and including those which may be equaled or exceeded on an average of once in a hundred years (100-year frequency). They are based on procedure set forth in the SCS National Handbooks on Hydrology. Any problems beyond the scope of the tables or figures herein, should be referred to the Area Engineer.

2. PEAK RATE

Definition

The peak rate as obtained by this procedure is the maximum, instantaneous rate of discharge for which spillways, waterways and conduits must be designed in order to pass a storm of a specified frequency.

Limitations

This procedure is applicable for estimating the peak rate of surface runoff from summer storms with reoccurrence intervals from two to one-hundred years (2 yr.-100 yr. frequency), and durations up to six hours. It is limited in size to watersheds having a time of concentration (T_c) of 6 hours or less. Any demands beyond the above limitations are provided for by the procedures in the SCS National Engineering Handbooks on Hydrology.

Data Required

Data required for the application of this procedure to a specific watershed is (1) rainfall expected from a 6-hour storm in inches, for a selected frequency; (2) size of the watershed in square miles; (3) runoff producing characteristics contained within the watershed which will be referred to as the soil cover complex number; and (4) the time of concentration, T_c, in hours which is the time required for water to travel from the most hydraulically distant point in the watershed to the point of design.

Rainfall Data - The 6-hour storm rainfall amounts for 2, 5, 10, 25, 50 and 100-year frequencies are shown on figure 3.1. In some cases the State Conservation Engineer may establish the 6-hour amounts for individual areas.

2. PEAK RATE (CONT'D)

Data Required (cont'd)

Watershed Drainage Area - Will be the size of area in square miles contributing surface runoff to the point of design. Fields having closed end, level terraces with 10-year frequency storage capacity can be considered as noncontributing for design storms up to the 10-year frequency, and the area omitted. Fields having open end level terraces should be included with the contributing area and treated the same as though they were gradient terraced.

Pot holes and the area contributing runoff to each, can be excluded from the computation for design frequencies of 10 years or less. For a design frequency of 25 years or more, the area above pot holes should be included as a part of the over-all drainage area.

In special cases, a portion of a drainage area may contain sandy or gravelly soils with such high intake rate and storage that runoff would not occur from the design storm. These areas should be considered noncontributing and excluded from the drainage area total.

Soil Cover Complex Number - These are shown in figure 3.2 for the range of watershed conditions most commonly encountered. Supplemental data to figure 3.2 may be required for special watershed conditions in some states. Figure 3.3 lists various soil names, common to the Great Plains States, under their appropriate hydrologic soil grouping, A, B, C or D. This figure may be supplemented in each state by soil codes more familiar to field personnel. All supplemental systems of soil codes should be correlated with the National system of name soils in figure 3.3 by the state soil scientist before being included as a part of this procedure.

The drainage area may be divided first according to hydrologic soil groups. Each of these divisions will have a distribution of land use, cover and treatment as shown in figure 3.2. The distribution should be determined on an area basis, obtained by a percent estimate of each in a hydrologic soil group. A soil cover complex number can be chosen from figure 3.2 for each subdivision and given a weight according to the area represented. The weighted parts will make up the composite soil cover complex number for the watershed as shown in the example on the "Sample Summary Sheet".

The soil cover complex numbers in figure 3.2 are for an average antecedent moisture condition. The technician may need to anticipate a wet antecedent moisture condition, under which the design storm will usually occur. This might be the case on irrigated fields or subirrigated seep areas. The soil cover complex number for these conditions will be ten times the square root of the number in figure 3.2.

The number for open end level terraced fields will be the same as though the terraces were gradient, and selected as a terraced item from figure 3.2. Fields with closed end level terraces will not be included

2. PEAK RATE (CONT'D)

Data Required (cont'd)

Soil Cover Complex Number (cont'd)

as part of the contributing area under certain conditions as explained for the "Watershed Drainage Area". For design frequencies under which areas with closed end level terraces are included, it should be treated as a terraced item in figure 3.2.

Contributing areas with a slope of less than one percent should be assigned a soil cover complex number equivalent to a contoured area.

Time of Concentration (T_c) - The correct determination of T_c is very important in the computation of peak discharge. The T_c for a given watershed may be found by measuring its hydraulic length and obtaining the average velocity of travel along its course.

$$T_c \text{ (hrs.)} = \frac{L \text{ (ft)}}{3600 \text{ V (ft/sec)}}$$

Where L = Hydraulic length of water travel from most distant point in the watershed.

V = Average velocity along the course of travel.

Figure 3.4 will be a guide in estimating average velocity.

For more refinement, the water course can be divided into reaches, velocity computed for each reach by Manning's equation, T_c's determined for each reach at channel capacity and then added together for the T_c from the hydraulically most distant point to the point of design.

Some of the factors to consider in estimating velocity are (1) slope or gradient of the water course, (2) characteristics of the channel, (3) type of land treatment and (4) condition of vegetative growth that would exist in and along the water course at the time of year when the large floods are most likely to occur.

Consideration of slope commences along the path of water travel at its most distant point in the watershed. The slope may be greater near the point of beginning than through any subsequent points. However, it may be overland flow (without a well defined channel) wherein land use, cover and treatment will have a very definite effect of retardance or high roughness coefficient.

If a channel is wide and shallow (in conformance to a shaping of vegetative waterways), velocities will be less than if the same sized channel was narrow and deep. The same relationship exists in meandering channels containing obstructions and dense vegetation as compared to straight clean channels. This is why straightened channels reduce the time of concentration (T_c) and result in higher peak discharges at downstream points.

2. PEAK RATE (CONT'D)

Data Required (cont'd)

Time of Concentration (cont'd)

Gradient terraces, open end level terraces or diversion ditches may simply extend the length of travel. The greatest length of water course will usually commence along one of the terrace channels. Velocity of travel will be approximately 1 foot per second along the terrace channel or diversion ditch due to the low gradient built into it.

Step Procedure for Computing Peak Rate Discharge

Every storm, against which the engineer is protecting the safety of his structure has its own unique pattern of distribution and duration. At this point it should be understood that the volume of runoff, peak discharge and inflow hydrographs in this section are developed from a standard 6-hour storm with intensities distributed according to the Weather Bureau's Technical Paper No. 25, December 1955. This was the basis for the zones on the map in figure 3.6.

Volume of Runoff - Volume of runoff (R) in inches, is read directly from the rainfall-runoff curves on figure 3.5. The rainfall amount is obtained from figure 3.1. The weighted soil cover complex number is determined as shown in the example. Runoff volume can be obtained for storms of longer duration, up to 24 hours, from figure 3.5, by entering the chart with the amount for the longer duration of precipitation.

Peak Discharge (cfs) - When only the maximum instantaneous discharge is required, it can be obtained from figure 3.7, for the zone shown in figure 3.6. First determine the time of concentration (T_c) and read from the appropriate column in figure 3.7, the unit peak discharge (q) for one square mile of drainage area and one inch of runoff (R). Using the volume of runoff (R) as described in the previous paragraph, the design peak discharge (Q) will be the product of:

$$Q = q\,A\,R$$

Where q is the unit peak discharge from figure 3.7 and for the appropriate zone in figure 3.6.

A is the drainage area in square miles.

R is the volume of runoff from a 6-hour storm in acre inches per acre from figure 3.5.

Hydrograph for Design Storm

In special cases a hydrograph of the design storm may be desirable. To plot a simple triangular hydrograph, use the unit peak discharge rate (q) for the watershed time of concentration (T_c) and compute the time to peak (T_p) by:

2. PEAK RATE (CONT'D)

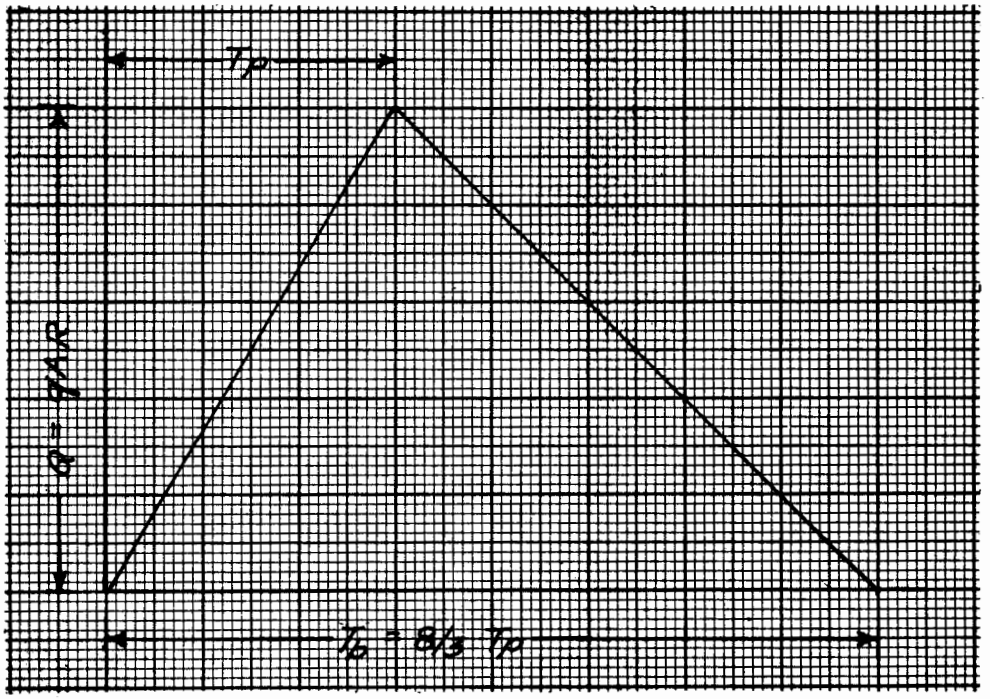
Hydrograph for Design Storm (cont'd)

$$T_p = \frac{484}{q} \text{ and } T_b = 2.67\ T_p$$

Where T_p = Elapsed time in hours from beginning of runoff to peak discharge.

T_b = Time of base.

q = The unit peak discharge from figure 3.7.



2. PEAK RATE (CONT'D)

Example of Procedure for Peak Rate Discharge

Required, the peak discharge for the design of an emergency spillway for a stockwater dam. It has a drainage area of 10,000 acres within which the range site and condition are the same as that used in the sample summary sheet on the following page. The greatest length of travel for surface runoff is 36,000 feet as measured on the aerial photograph. The channel is similar to Case III on figure 3.4 and has an average slope of 4 percent. The spillway is to be designed to pass a 50-year storm frequency.

1. Weighted Soil Cover Complex Number (from sample summary sheet)..76

2. Precipitation, P, (from figure 3.1).....2.5"

3. Volume of runoff, R, (from figure 3.5).....0.75"

4. Average velocity of travel, V, (from figure 3.4 Case III).....6 ft/sec.

5. Time of concentration, T_c,.....1.7 hrs.

$$T_c \text{ (hrs.)} = \frac{36{,}000 \text{ ft}}{3600 \times 6 \text{ ft/sec}} = 1.67$$

6. Unit peak discharge q, (from figure 3.7 for Zone 3, figure 3.6) for T_c = 1.67 hr.....245 cfs

7. Peak discharge, Q, for watershed.....2870 cfs

$$Q = 245 \left(\frac{10{,}000}{640}\right) (0.75) = 2870 \text{ cfs}.$$

8. Time to peak.....2.0 hrs.

$$T_p = \frac{484}{245} = 1.98 \text{ hrs.}$$

9. Time of base.....5.3 hrs

$$T_b = 2.67 \ (1.98) = 5.26$$

(SAMPLE SUMMARY SHEET)

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

(State Form Number)

Structure No. 2 Able Ranch (Watershed or Structure Name) Total Drainage Area 10,000Ac.

Date 1-1-60

Compiled by John Doe

Basic Data for Determining
Weighted Soil Cover Complex Number

Range Site (1)	Condition (2)	Soil Cover Complex No. (Number) (3)	Percent of Area (4)	Complex No. Times Area (Cols 3 x 4) (5)
Savannah	Low	80	60	4800
Choppy Sand	Low	70	40	2800
Totals		100		7600

Weighted Soil Cover Complex No. is $\frac{\text{(Total Col. 5)}}{\text{(Total Col. 4)}}$ or 76

Time of Concentration - 1.7 hrs.

Rainfall (6 hr.) 50 yr. frequency, 2.5 inches.

Runoff Volume (R) 0.75 inches.

Unit Peak Discharge (q) 245 cfs per square mile per inch of runoff.

Peak Discharge (Q) - 2870 cfs.

Hydrograph (if required) attached.

3-8
(Colo)
(Wyo)
(Mont)

Expected Storm Rainfall in Inches
From Six Hour Storm

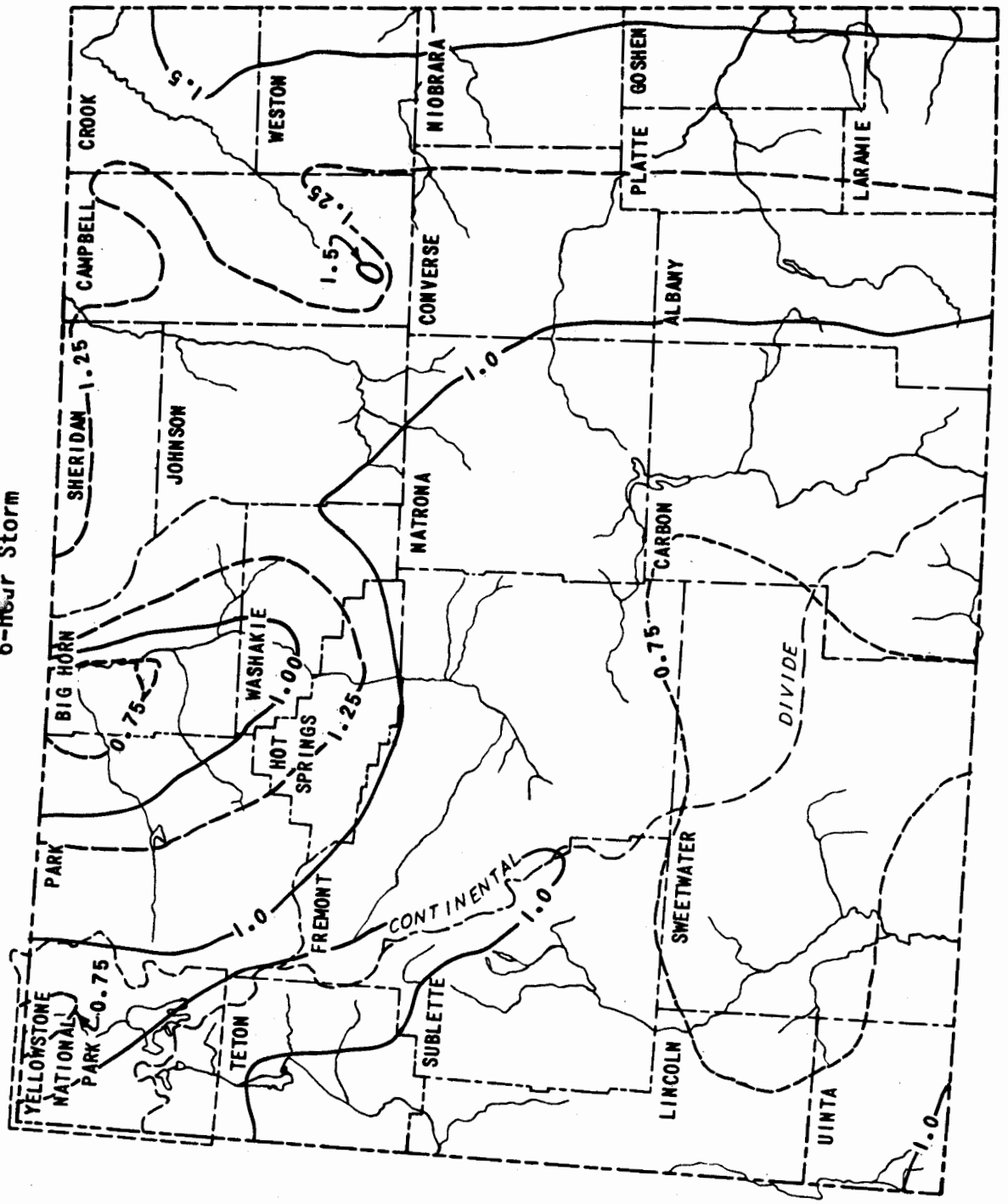
To be Read from US Weather Bureau
Technical Paper No. 28

Figure 3.1

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

WYOMING

Expected Storm Rainfall in Inches
6-Hour Storm



2 Year Frequency

Figure 3.1

Reference: Weather Bureau Technical Paper No. 28

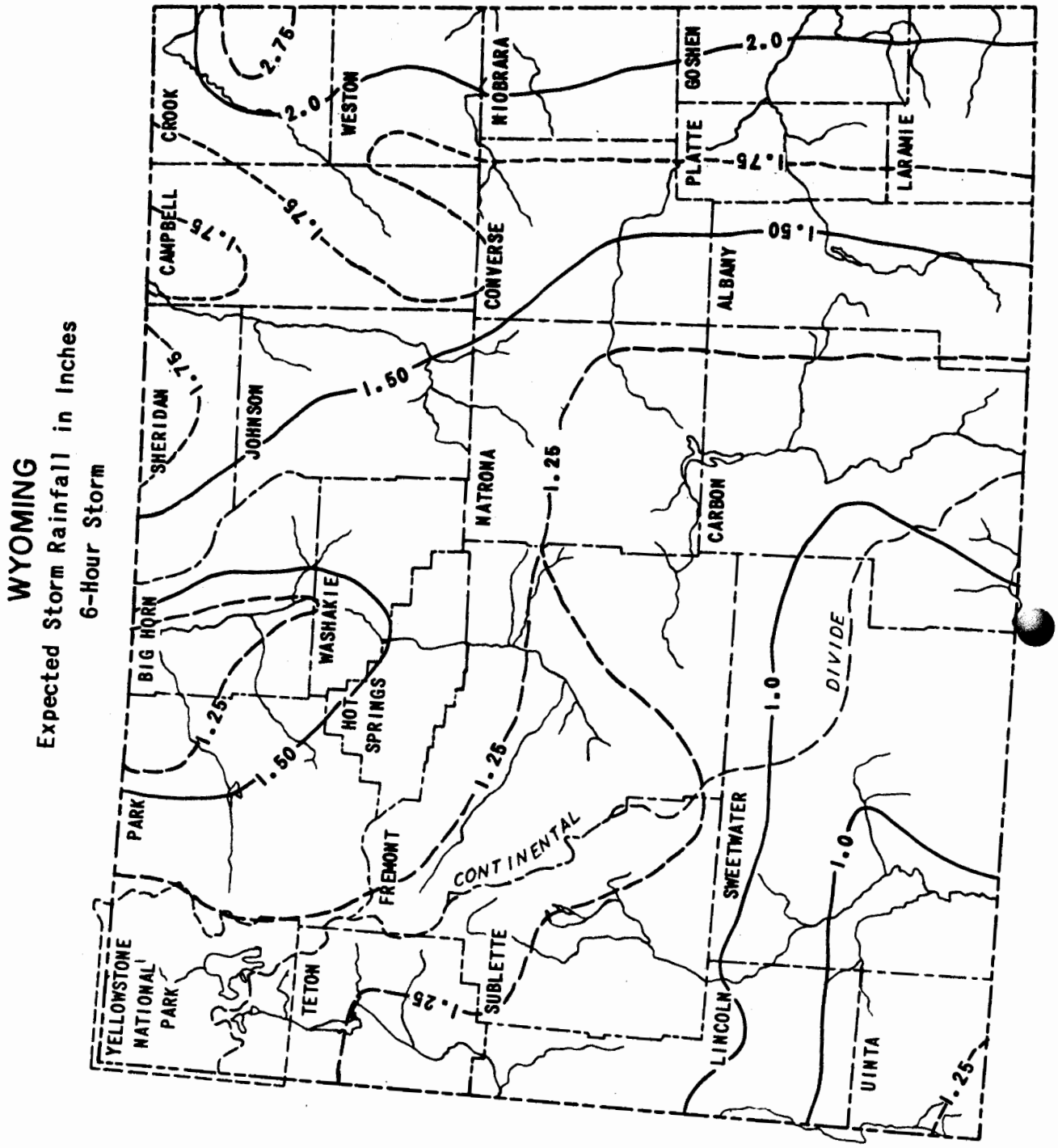


Figure 3.1

Reference: Weather Bureau Technical Paper No. 28

USDA-SCS-LINCOLN, NEBR. 1959

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

WYOMING
Expected Storm Rainfall in Inches
6-Hour Storm
10 Year Frequency

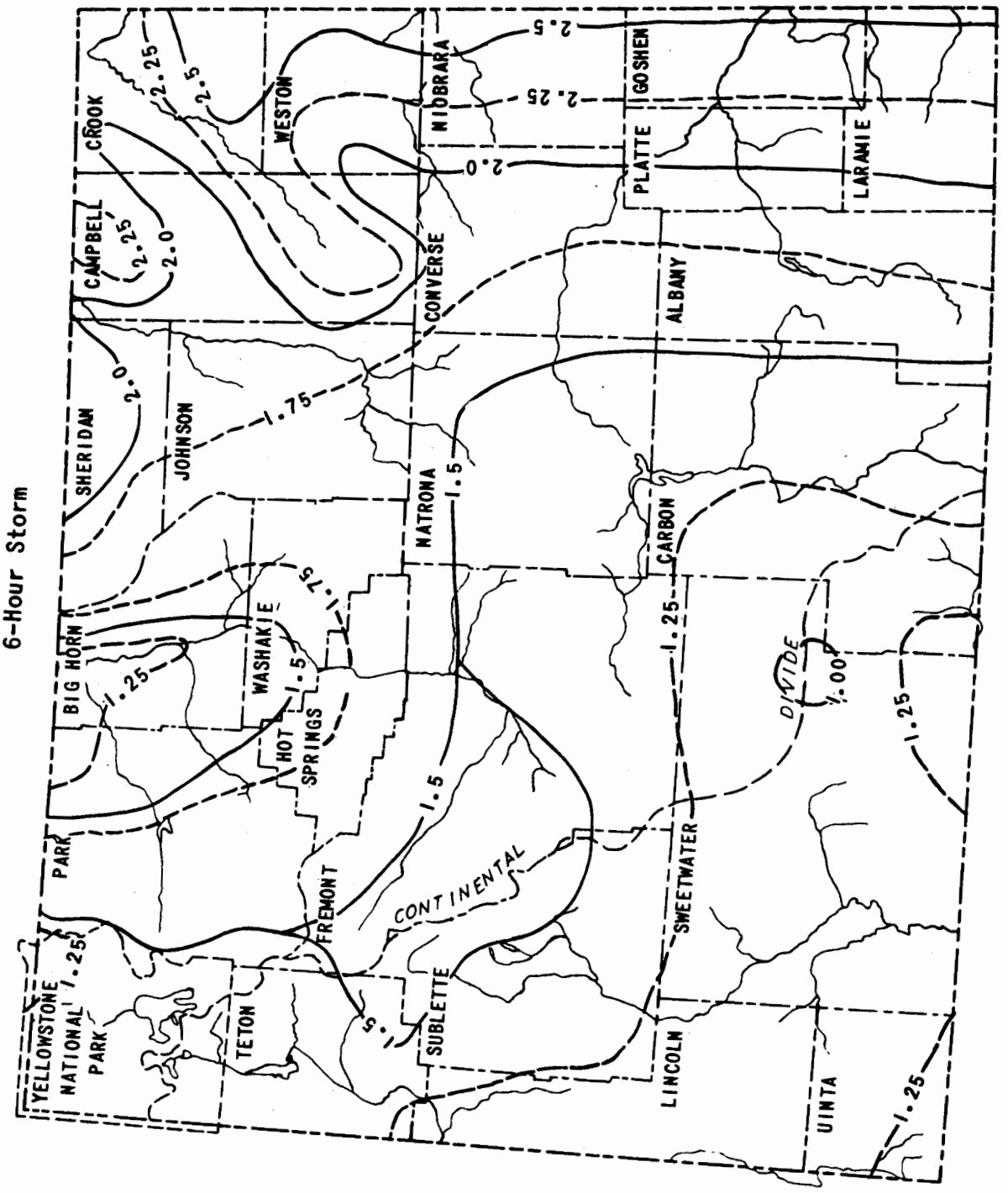


Figure 3.1

Reference: Weather Bureau Technical Paper No. 28

5,L-16,014-4(6)

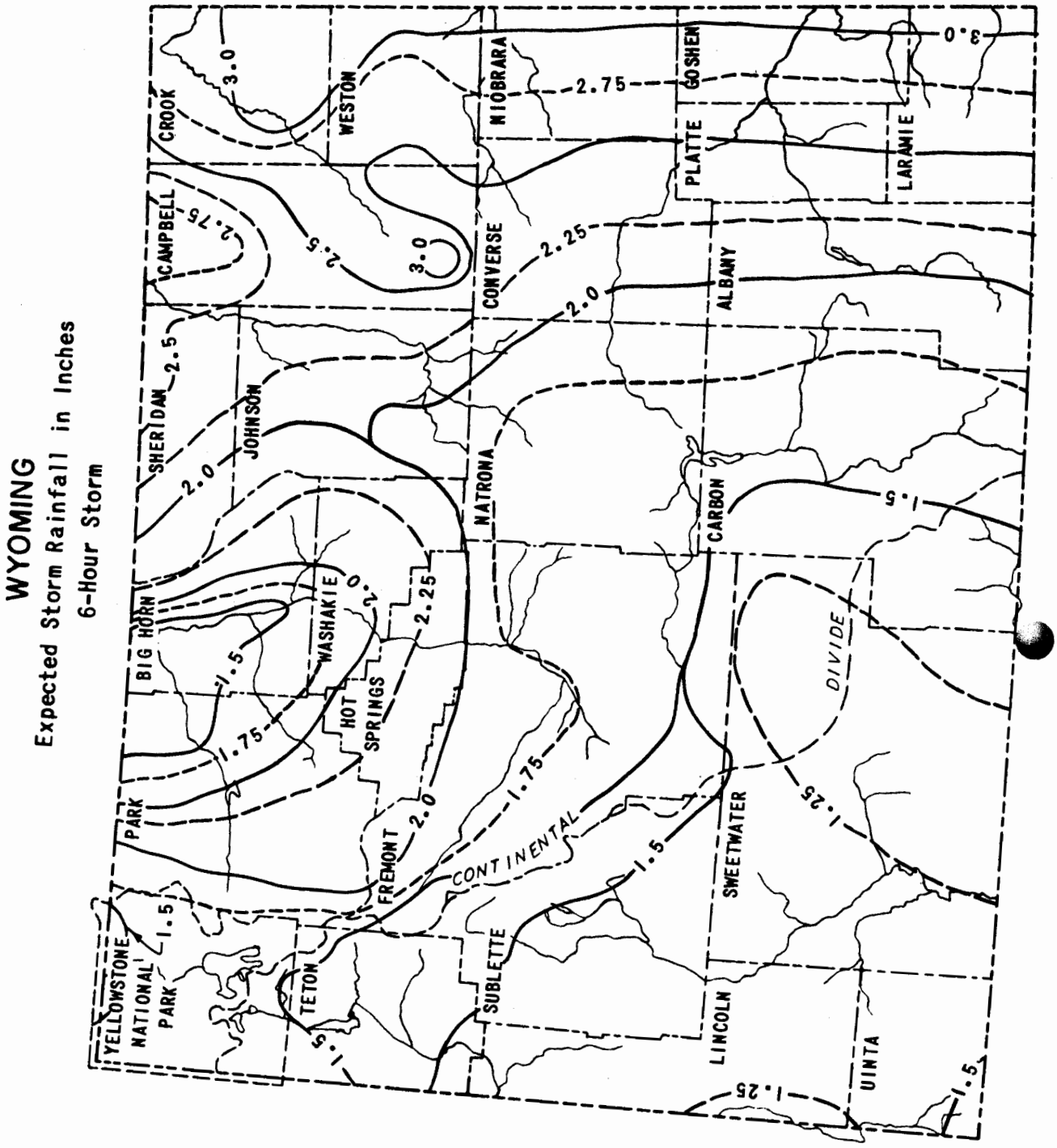


Figure 3.1

Reference: Weather Bureau Technical Paper No. 28

USDA-SCS-LINCOLN NEBR. 1959

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

WYOMING
Expected Storm Rainfall in Inches
6-Hour Storm
50 Year Frequency

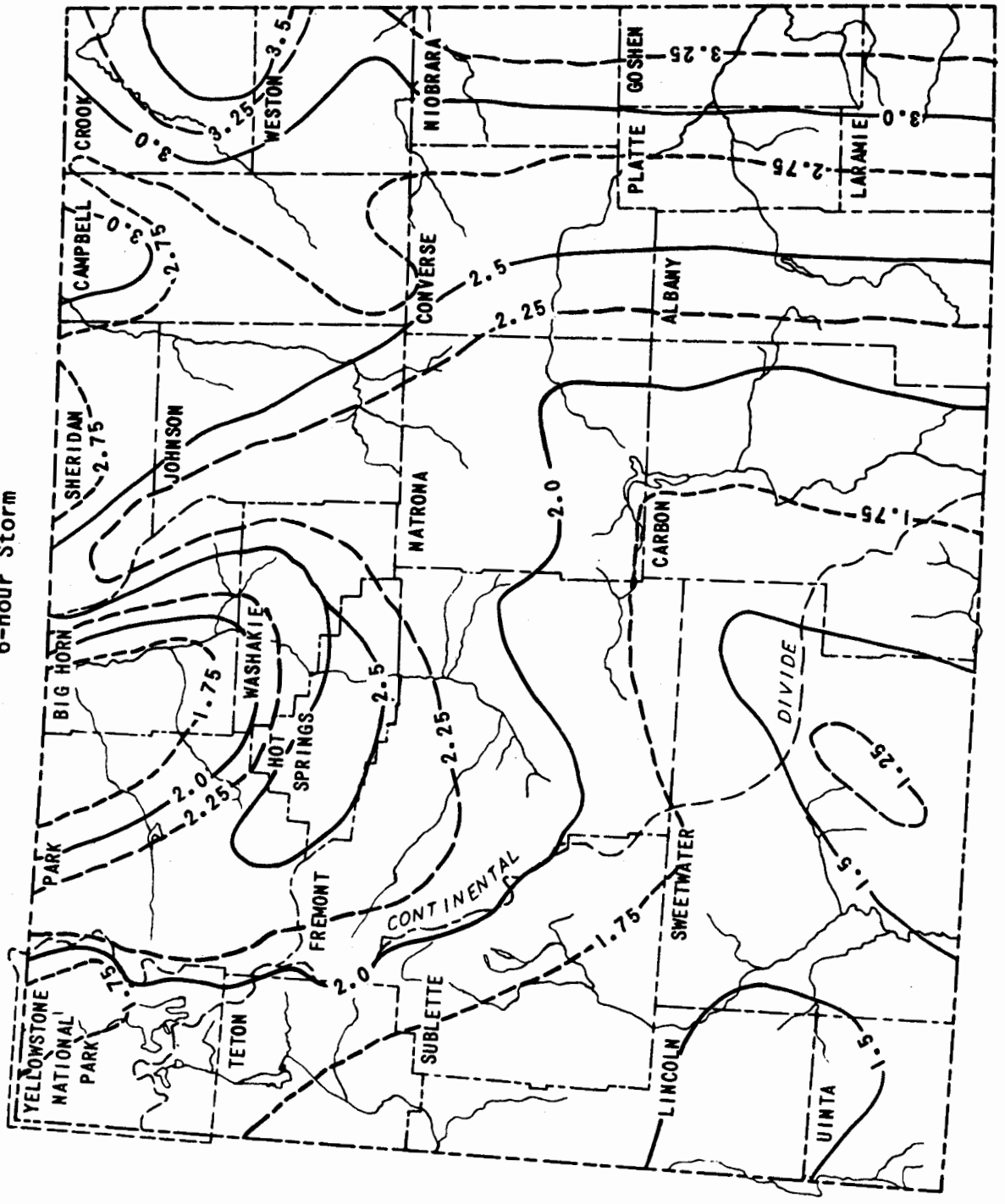


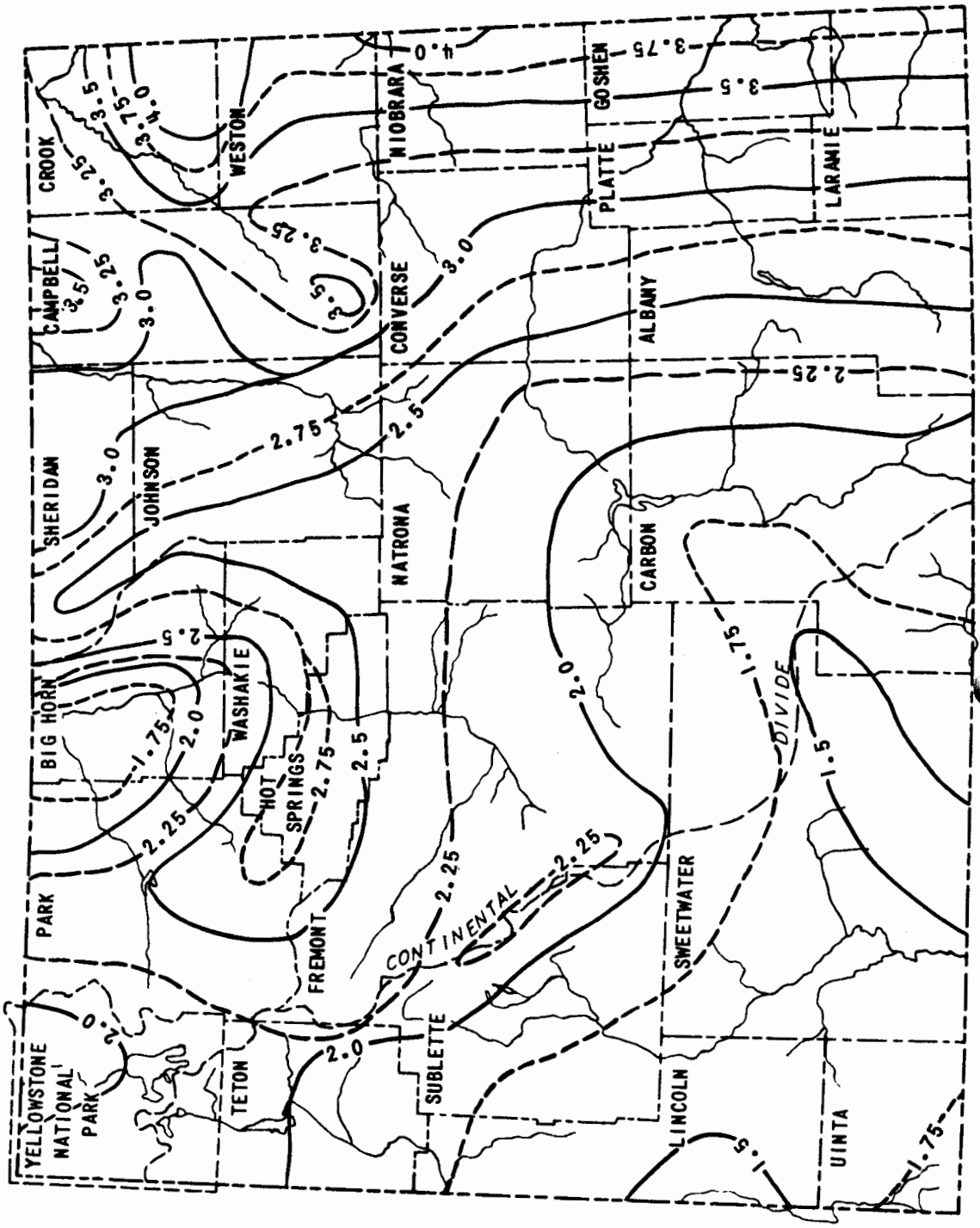
Figure 3.1

Reference: Weather Bureau Technical Paper No. 28

5,L-16,014-2(6)

WYOMING

Expected Storm Rainfall in Inches
6-Hour Storm



100 Year Frequency

Figure 3.1

Reference: Weather Bureau Technical Paper No. 28 USDA-SCS-LINCOLN, NEBR. 1959

5,L-16,014-1(6)

2. PEAK RATE (CONT'D)

Soil Cover Complex Numbers

Land use or cover	Treatment or practice	Hydrologic condition	Hydrologic soil group A	B	C	D
Fallow 1/	Straight row	- - -	77	86	91	94
Row crops	"	Poor	72	81	88	91
	"	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	"	Good	65	75	82	86
	" and terraced	Poor	66	74	80	82
	" " "	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	" "	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	"	Good	61	73	81	84
	" and terraced	Poor	61	72	79	82
	" " "	Good	59	70	78	81
Close-seeded legumes 2/ or rotation meadow	Straight row	Poor	66	77	85	89
	" "	Good	58	72	81	85
	Contoured	Poor	64	75	83	85
	"	Good	55	69	78	83
	" and terraced	Poor	63	73	80	83
	" and terraced	Good	51	67	76	80
Pasture or range		Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	"	Fair	25	59	75	83
	"	Good	6	35	70	79
Meadow (permanent)		Good	30	58	71	78
Woods (farm woodlots)		Poor	45	66	77	83
		Fair	36	60	73	79
		Good	25	55	70	77
Farmsteads		- - -	59	74	82	86
Roads (dirt) 3/		- - -	72	82	87	89
(hard surface) 3/		- - -	74	84	90	92

1/ Good stubble mulch fallow can be treated same as small grain.
2/ Close-drilled or broadcast.
3/ Including right-of-way.
See general notes on next page.

Figure 3.2

2. PEAK RATE (CONT'D)

(Use in areas where range surveys are made in lieu of detailed soils maps)

Range Site 1/	Range Condition	Soil Cover Complex Number
Subirrigated, wet land & very shallow sites	High	90
	Low	95
Badlands, shale, saline upland, panspots & clayey sites	High	80
	Low	90
Thin loess, thin breaks & silty sites	High	75
	Low	85
Stonyhills, savannah & sandy sites	High	60
	Low	80
Choppy sand and sand sites	High	40
	Low	70
Gravel sites	High	25
	Low	45

1/ Described in E. J. Dyksterhuis' letter to Range Conservationists, Northern Plains States, Dec. 20, 1954.

Figure 3.2 (cont'd)

2. PEAK RATE (CONT'D)

Hydrologic Soil Groups

GROUP A

(Includes deep sands with very little silt and clay; also deep, rapidly permeable loess)

Balls loamy fine sand
Dune sand
Dwyer fine sand
Flasher fine sand
Haskill fine sand
Lihen loamy fine sand
Roosville sand
Tivoli sand and loamy sands
Valentine fine sand
Vebar fine sand
Vona

GROUP B

(Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting)

Albien
Amsterdam silt loam
Badrock gravelly loam
Bates
Battrick stony loam
Beaverton gravelly loam
Blodgett
Breece
Canyon
Cheyenne
Colby
Creston
Cushman
Dalhart fine sandy loam
Darnell stony fine sandy loam
Farland
Flathead
Geary
Gilcrest
Glendive
Grant
Grantsdale
Half Moon
Hamilton
Holdrege
Keith
Lancaster
Larimer
Lihen fine sandy loam
Lolo
Marshall
Morton
Musselshell
Otero
Scobey
Sogn
Terry
Whitefish
Williams
Woodside
Zahl

Figure 3.3

2. PEAK RATE (CONT'D)

Hydrologic Soil Groups

GROUP C

(Comprises shallow soils and soils containing considerable clay and colloid, though less than those of Group D. The group has below-average infiltration after pre-saturation)

Big Timber
Briggsdale
Burchard
Butler
Cabinet
Crete
Danvers
Dennis
Edalgo
Florence
Goessel
Grail
Grundy
Hastings
Heath
Idana
Labette
Little Timber
Marias
Midnay
Nunn
Prior
Regent
Richfield
Savage
Shelby
Steinauer
Summit
Valier
Weld

GROUP D

(Includes mostly clays of high swelling percent; but the group also includes some shallow soils with nearly impermeable subhorizons near the surface)

Arvada
Badlands
Cherokee
Kirkland
Ladysmith
Lismas
Neosha
Osage
Parsons
Pawnee
Phillips
Pierre
Post
Ravalli
Rhoades
Wade

Figure 3.3 (cont'd)

VELOCITY OF TRAVEL IN SELECTED CHANNELS

CASE I

CASE II

CASE III

CASE IV

CASE V

Figure 3.4

Velocity of Travel

For Cases I and III		For Cases I and III (cont'd)	
Av. Channel Slope (Percent)	Velocity (feet per second)	Av. Channel Slope (Percent)	Velocity (feet per second)
0.5	2	5	7
1.0	3	6	8
2.0	4	7	9
3.0	5	8	10
4.0	6	10	11

For Cases II and V		For Cases II and V (cont'd)	
Av. Channel Slope (Percent)	Velocity (feet per second)	Av. Channel Slope (Percent)	Velocity (feet per second)
0.5	3	5	10
1.0	5	6	11
2.0	7	7	12
3.0	8	8	13
4.0	9	10	15

For Case IV	
Av. Channel Slope (Percent)	Velocity (feet per second)
0.5	5
1.0	7
2.0	10
3.0	13
4.0	15
5.0	17

Figure 3.4 (cont'd)

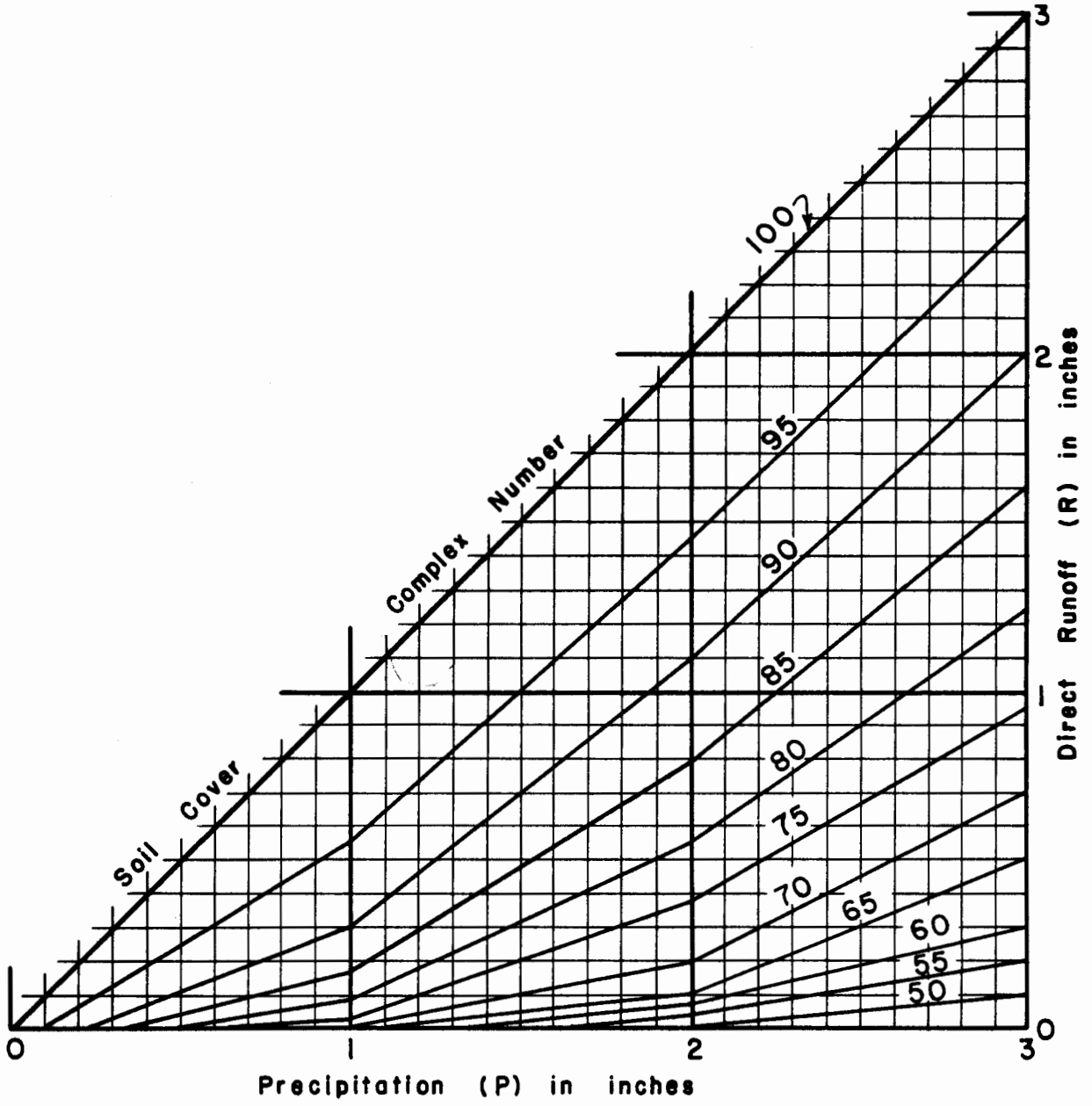

Soil Cover Complex Number
100
95
90
85
80
75
70
65
60
55
50
0
1
2
3
Precipitation (P) in inches
Direct Runoff (R) in inches

Figure 3.5

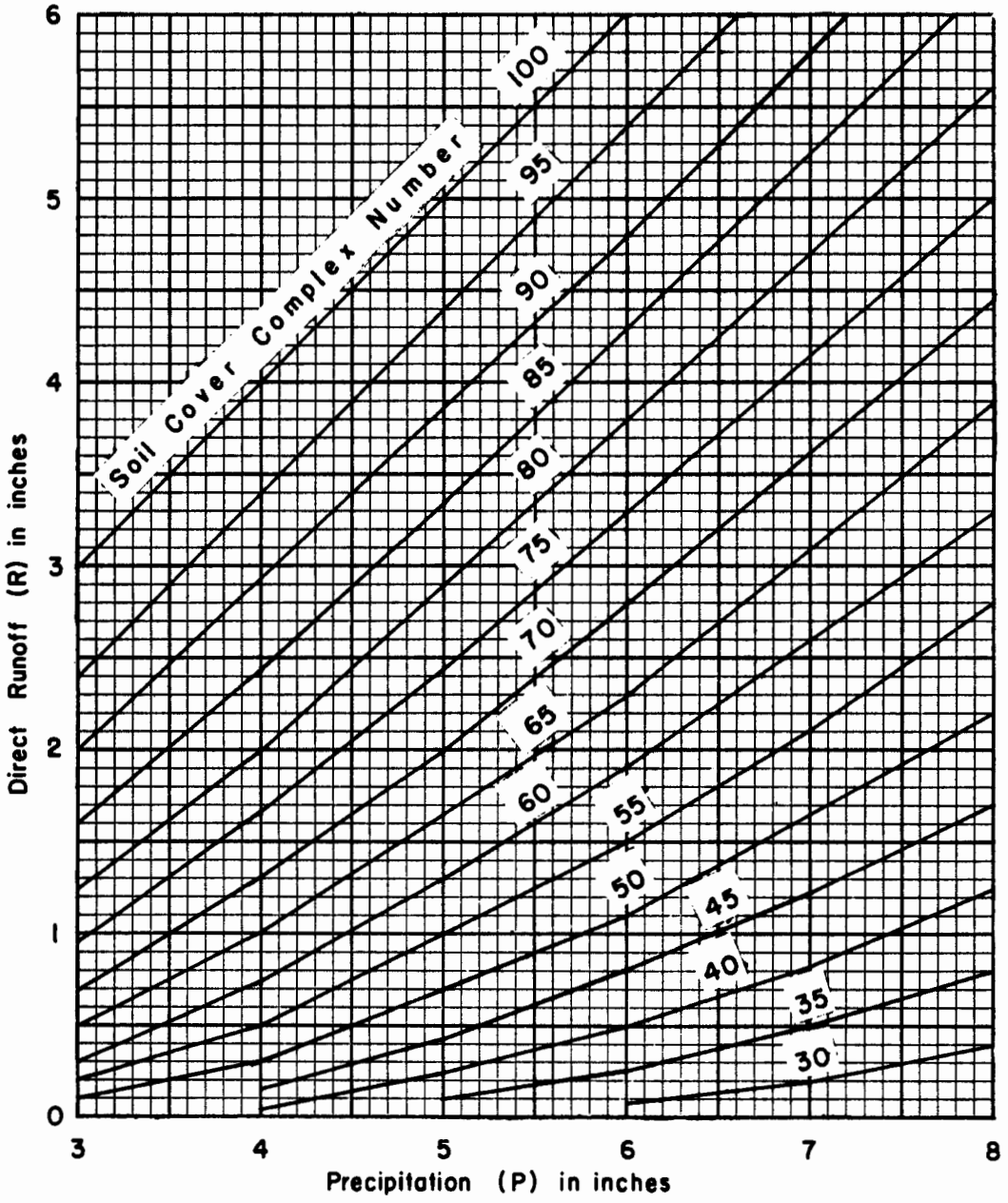


Figure 3.5 (cont'd)

RAINFALL INTENSITY DISTRIBUTION ZONES

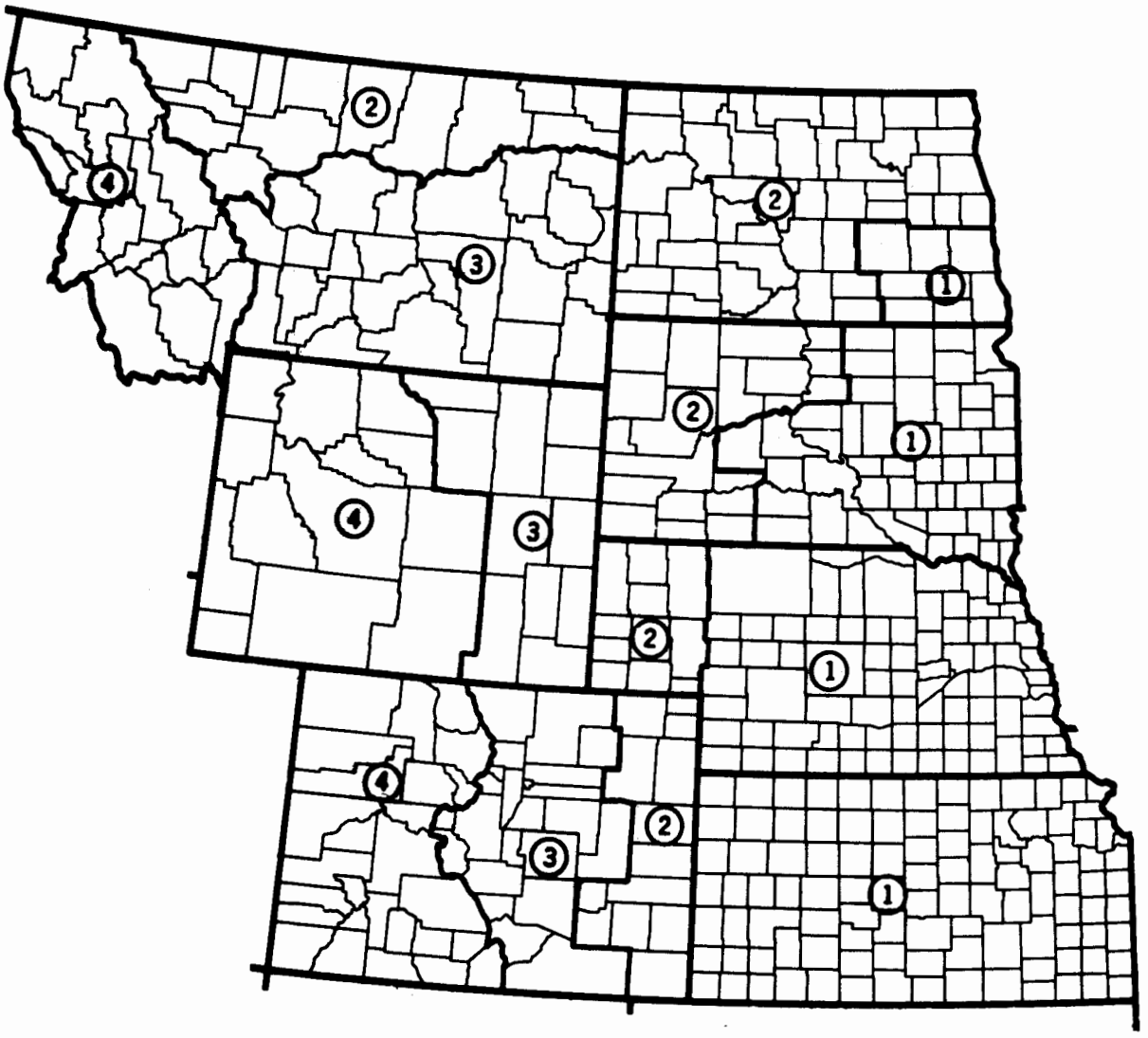


Figure 3.6

2. PEAK RATE (CONT'D)

Unit Peak Discharge Versus Time of Concentration

T_c (hours)	q cfs/(mi²)(in)[1/] Zone 3	Zone 4	T_c (hours)	q cfs/(mi²)(in)[1/] Zone 3	Zone 4
0.10	900	520	0.5	440	255
0.12	830	480	0.6	410	235
0.14	780	450	0.7	380	220
0.16	730	425	0.8	360	210
0.18	700	400	0.9	340	200
0.20	670	385	1.0	330	190
0.22	640	370	1.2	300	175
0.24	610	355	1.4	275	160
0.26	590	340	1.6	255	155
0.28	570	330	1.8	235	145
0.30	555	320	2.0	220	140
0.32	540	310	2.5	190	125
0.34	525	300			
0.36	510	295	3.0	165	115
0.38	500	290	3.5	145	110
0.40	490	285	4.0	130	105
0.42	480	280	4.5	120	100
0.44	470	275			
0.46	460	265	5.0	110	95
0.48	450	260	5.5	100	90
			6.0	95	85

1/ (in) = acre inch runoff per acre.

Figure 3.7

CONTENTS

PART 4

TERRACING

	Subject	Page
1.	General	4-1
	Definition	4-1
	Applicable State Laws	4-1
	Uses and Limitations	4-1
	Function of Terraces in Conservation Program	4-1
	Limitations of Terraces	4-3
	Conditions for Level Terraces	4-3
	Conditions for Graded Terraces	4-3
	Conditions for Pasture Terraces	4-3
2.	Surveys for Basic Data Collection	4-3
	Soil Surveys	4-3
	Physical Inspection	4-4
	Topographic Surveys	4-4
3.	Designing the Terrace System	4-5
	General	4-5
	Terrace Grade and Length	4-5
	Graded Terraces	4-5
	Level Terraces	4-7
	Location of the Terrace Outlets	4-7
	Factors to Consider	4-7
	Pastures and Meadows	4-8
	Natural Waterways	4-8
	Side Field Cuts of Constructed Channels	4-11
	Structural Terrace Outlets	4-11
	Roads and Lanes	4-11
	Cross Section Requirements	4-12
	Terrace Cross Sections	4-12
	Terrace Intervals	4-13
	Using Terrace Spacing Formula	4-13
	Using Universal Soil Loss Equation	4-13
4.	Layout of Terrace System	4-16
	General	4-16
	The Key Terrace	4-18
	Staking the Graded Terrace Outlet	4-18
	Determining the Vertical Interval	4-19

(Rev. 11/64)

CONTENTS (CONT'D)

PART 4

TERRACING

Subject	Page
4. Layout of Terrace System (cont'd)	
Relation of the Staked Line to the Completed Terrace	4-20
Graded Terrace	4-20
Level Terrace	4-20
Adjustments to Improve Terrace Alignment	4-20
Paralleling Terraces	4-21
System 1 - Uniform Slopes	4-21
System 2 - Irregular Slopes	4-22
Staking Cuts or Fills Where Alignment is Improved	4-26
5. Construction of Terraces	4-28
Preparation of the Field	4-28
Methods of Terrace Construction	4-28
Building Terraces with a Motor Grader	4-28
Building Terraces with a Moldboard Plow	4-28
Building Terraces with a Disc Tiller	4-33
Constructing Terraces with an Elevator Terracer	4-36
Bulldozer	4-38
Checking the Finished Terrace	4-38
6. Terrace Maintenance	4-38
Control of Inter-Terrace Erosion	4-38
Repair of Fills in Terrace Ridge	4-40
Removal of Silt Bars from Terrace Channels	4-40
Increasing Terrace Ridge Height	4-40
Plowing for Terrace Maintenance	4-40
Cleaning Channels with Terrace Construction Equipment	4-42
7. Farming Terraced Fields	4-42
Planting Row Crops on Terraced Land	4-42
a. Method 1	4-42
b. Method 2	4-44
c. Method 3	4-46
Harvesting Crops on Terraced Land	4-46
Harvesting Small Grain	4-46
Harvesting Corn or Grain Sorghum	4-49
Harvesting Hay	4-51

LIST OF FIGURES

PART 4

TERRACING

Figure Number	Title	Page
4.1	Staking a Terrace Outlet	4-6
4.2	Typical Terrace Outlets	4-9
4.3	Methods of Water Disposal	4-10
4.4	Volume of Runoff in Cubic Feet Per Linear Foot	4-12
4.5	Values of x in Equation V.1 = xsty	4-14
4.6	Avoiding Sharp Bends	4-16
4.7	Improving Terrace Alignment	4-17
4.8	Terrace Layout	4-24
4.9	Revised Terrace Layout	4-25
4.10	Pattern of Land Use and Expected Soil Loss Per Acre for Specified Rotations and Practices on Marshall Silt Loam Soils Where the Dominant Slopes Are About Nine Percent	4-27
4.11	Terrace Construction by Patrol Grader	4-29
4.12	Terrace Construction by Patrol Grader	4-30
4.13	Terrace Construction	4-31
4.14	Terrace Building With 2-Bottom Tractor Moldboard Plow	4-32
4.15	Diagram of Operations Showing Construction of a Terrace With a 4 Ft. Disc Tiller, Slopes 8 to 12%	4-35
4.16	Terrace Construction by Elevator Grader or Terracer	4-36
4.17	Terrace Construction by Elevator Grader or Terracer	4-37
4.18	Terrace Construction by Elevator Grader or Terracer	4-37
4.19	Method for Terrace Construction With Bulldozer	4-39
4.20	Plowing for Terrace Maintenance	4-41
4.21	Planting Row Crops on Terraced Land, Method 1	4-43
4.22	Planting Row Crops on Terraced Land, Method 2	4-45
4.23	Planting Row Crops on Terraced Land, Method 3	4-47
4.24	Small Grain	4-48
4.25	Corn	4-50

PART 4

TERRACING

1. GENERAL

Definition

A terrace consists of a channel supported by an earthen ridge built across a slope to intercept surface runoff water. It may be constructed either as a graded or level channel and ridge.

a. A gradient terrace is one constructed so that it will have a grade, either variable or uniform, to conduct intercepted water at a non-erosive velocity to a suitable outlet where it can safely be disposed of.

b. A level terrace is one constructed on a true contour where the channel and ridge create an impounding reservoir. The water is permitted to seep into the soil. Level terraces may be closed at the ends or left open to drain.

Applicable State Laws

Consideration must be given in the planning and installation of terrace systems to the applicable State Laws which govern the diversion of water. Generally water must not be diverted whereby it leaves one ownership at a point other than the natural watercourse.

Uses and Limitations

Function of Terraces in Conservation Program. Terraces are of value on practically all soil types except soils that are too stony, sandy, or shallow to permit practical and economical installation and maintenance. If properly located, constructed and maintained, terraces will assist in conserving the soil. They reduce runoff and soil losses and prevent the formation of rills and gullies. They assist in the reclamation of badly gullied fields by intercepting the runoff before it becomes concentrated and attains sufficient velocity to erode the soil. Terraces save the topsoil and prevent the loss of costly seed and plant foods. To be effective, they must be used in combination with other practices such as stubble mulching, contouring, and stripcropping. Over a period of years, better crops may be expected on terraced than on unterraced land because of the soil and moisture that they save.

Land is subject to erosion of varying degrees depending upon
(1) the steepness of the land and length of slopes,
(2) the intensity and volume of rainfall,
(3) the character of the soil,
(4) the crops grown and the method of cultivation,
(5) the amount and type of cover that is maintained.

1. GENERAL (CONT'D)

Function of Terraces in Conservation Program (cont'd)

If soil erosion cannot be controlled on a field by contour farming, stripcropping, stubble mulching and good cropping practices, it is necessary to include terraces as a land treatment practice.

Terraces are normally used only on cultivated lands. However, some badly eroded lands that are to be retired to grass are so severely gullied that it is difficult to get grass established. Runoff waters in gullies and on steep slopes wash out small seedlings before the grass becomes firmly established. In such instances, terraces to divert or store runoff are necessary.

It is not advisable to terrace some lands where
(1) the slope of the land is excessive,
(2) the soils are too sandy, too stony, or too shallow to permit economical construction and maintenance of a terrace system,
(3) the topography is extremely irregular.

The steepness of the land is one of the factors that determines the practicability of terraces. As the slope of land increases, soil losses from erosion increase, but it also becomes more difficult and more costly to control erosion by means of terraces. The cost of maintenance and the difficulty of farming operations increase with the degree of slope to the point that they eventually outweigh the benefits derived. When this point is reached, terracing is not practicable. At the other end of the slope scale, some long slopes as gentle as one-half foot per 100 feet need terraces to prevent erosion because of the concentration of water down the slope.

The steepest slope on which terracing is practical is not determined by empirical formula but by the intelligence, industry, and the accompanying conservation practices applied by the operator as well as by economic conditions. Drainage terraces are being successfully employed on slopes as steep as 12 percent on residual and glacial soils and on slopes up to 20 percent on loess soils providing proper land use is observed.

Frequently the less productive soils are terraced or terracing is delayed until the soil has become so badly gullied and eroded that construction is costly, maintenance is excessive, and farming operations are difficult. If these conditions are prevalent in a community, terracing may frequently be looked upon with disfavor. Terraces pay the smallest proportional returns when used to reclaim fields that have already been badly eroded and gullied.

Farmers will not follow terrace lines that are constructed on extremely irregular slopes and, therefore, these slopes should be avoided when terraces are planned.

1. GENERAL (CONT'D)

Limitations of Terraces. Terraces will not eliminate the need for good crop rotations in maintaining soil structure and fertility. They will not replace the need for contouring. They should be used only on soils and slopes where shown as applicable in SCS State and local technical guides.

Conditions for Level Terraces. Level terraces are applicable where it is desirable to prevent the loss of moisture by runoff. They require the practice of a good soil management program to maintain a high organic matter content and to prevent surface sealing of the soil. The soil must have a high rate of infiltration and permeability so as to readily absorb and store water. The average annual rainfall generally should not exceed 25 to 30 inches depending on the soil depth and texture. Adequate available terrace outlets must be available where the ends of level terraces are left open.

Level terraces are particularly adaptable to the semiarid portions of the region for water conservation. They are also used as a soil conservation measure in all areas of suitable soils where outlets are a problem and runoff must be kept to a minimum or entirely eliminated from natural channels. They have been functioning successfully on slopes as steep as 12 percent.

Conditions for Graded Terraces. Graded terraces are applicable where it is desirable to dispose of the surface water that reaches the terrace channel. Suitable stabilized outlets are available in a natural watercourse, shaped waterway, pasture, or meadow having sufficient cover and adequate width to prevent erosion. The topographic and soil conditions must be suitable and practical for cultivation before as well as after terraces are constructed. Such companion practices as contour farming, good crop rotations, and stubble mulching must be used.

Conditions for Pasture Terraces. In general, land being removed from cultivation and recommended for use as pasture because of land classification (with the exception of Class V) is land which is steep, shallow, or rough and irregular. It usually has suffered severe erosion because of misuse. Terraces are frequently needed to stabilize the soil and allow adequate seedbed preparation in these cases. Pasture terraces are recommended only if these conditions are present.

2. SURVEYS FOR BASIC DATA COLLECTION

Soil Surveys

Soil surveys are needed before planning and design of the terrace system is started. Through use of the conservation survey map to determine the land classification and the needed conservation use and treatment, the adapted type of terrace can be selected.

2. SURVEYS FOR BASIC DATA COLLECTION (CONT'D)

Physical Inspection

A terrace system properly planned and installed in accordance with a complete conservation farm plan becomes a valuable improvement. The first step in planning a terrace system is to make a thorough physical inspection of the area under consideration and for the larger projects to prepare a sketch map on which are located all the topographical features such as drainageways, ridges, slopes, hills, gullies, fields and property lines, roads, buildings, fences, and any other features that may influence the layout of the system. If a sketch map is used, it may consist of a map prepared from information secured either by a physical inspection, hand level, pacing survey, or of a complete topographic map of the area.

In making preliminary surveys, each field should be examined for any depressions that would require a terrace fill. Such depressions should be filled or shaped by plowing toward the depression. It may be desirable to plow and float the field to eliminate minor surface irregularities. These operations can be done most efficiently before terraces are laid out and constructed. The amount of water impounded above a terrace fill will thereby be reduced and the resulting reduction of wet areas will facilitate farming operations.

Topographic Surveys

Sufficient surveys should be made so that each terrace system can be properly planned. Sometimes merely a contour line will be sufficient to determine the terrace pattern. In the more complex layouts in order to get the best layout possible, it may be necessary to have a complete topographic survey or a preliminary layout of the system in the field. Where this kind of survey is needed or required, terrace systems may be planned on the contour map and then staked in the field according to the paper layout.

The need for a topographic field map other than an aerial photograph will depend upon the experience of the field man, the size of the project, and the nature of the topographical features encountered. Engineers or other technicians with sufficient field experience may often dispense with the actual preparation of the field map if the topographical features encountered do not make terracing unduly difficult.

In planning farms on which there are existing terraces, a check with instruments should be made of a sufficient number of those terraces to determine what part of the old system can be used. When only sections of an existing terrace are suitable for use careful surveys are needed to insure that the new sections properly tie into the existing sections that are used.

3. DESIGNING THE TERRACE SYSTEM

General

Insufficiently considered and hastily prepared plans usually result in unsatisfactory layouts. The importance of determining the most satisfactory plan lies in the fact that terraces, once constructed, become permanent farm structures if properly maintained.

In planning a system all necessary terracing for the entire farm should be considered in order that terracing on any part of the farm may be fitted into the complete terrace system without difficulty or unnecessary expense. The possibility of rearrangement of fields, fences, and roads to conform to good land utilization and farm management policies should be kept in mind.

Adjacent farms may often have fields in the same drainage unit in which case a joint terracing system may be used to advantage for both fields provided a satisfactory agreement can be made between the two landowners for joint construction and maintenance of the terraces and outlets. Such agreements should be in written form.

Soil factors such as depth, texture, permeability, slope, erosion, wetness, alkalinity and salinity, as well as tillage and cultural practices must be given careful consideration in planning and designing the terrace system.

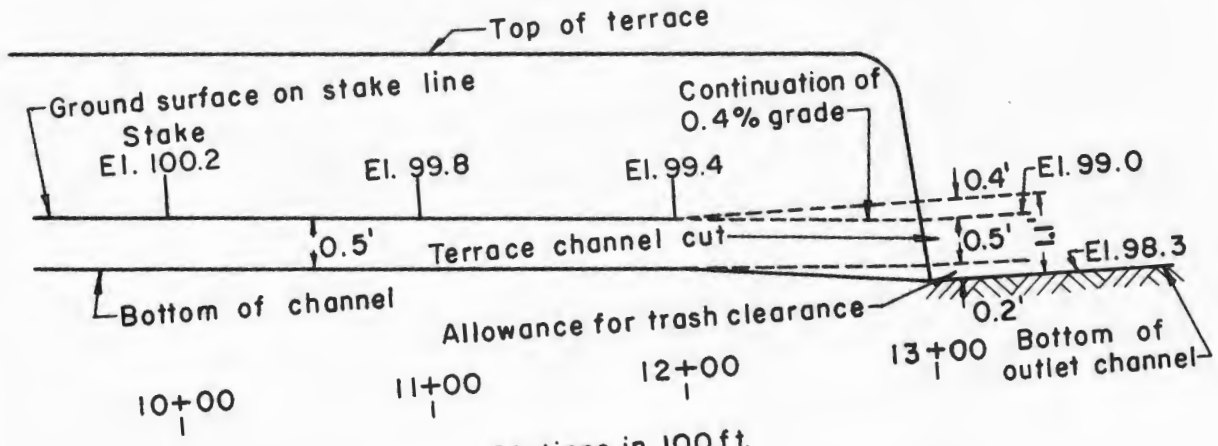
Terrace Grade and Length

Graded Terraces. Graded terraces act primarily as drainage channels to conduct excess rainfall from the fields at nonerosive velocities to stabilized outlets or waterways. Grades should be sufficient to provide good drainage and develop adequate flow without scouring the channel and washing out crops. If the grades are not sufficient, a waterlogged condition will occur, crops will be drowned out, and farm operations made difficult. Grades may be uniform or variable with a maximum of 0.6 feet per 100 feet.

The final 50 or 100 feet of a graded terrace should have an increase in grade to overcome outlet restrictions and allow for the depth of the terrace channel. (See Figure 4.1)

It is customary to change the rate of grade at intervals of from 300 to 500 feet. Thus, a terrace 1,300 feet long might have the following rates of grade: Commencing at the upper end, 0 to 400 feet - 0.2%; 400 to 800 feet - 0.3%; 800 to 1,200 feet - 0.4%; 1,200 to 1,300 feet - 0.9%.

Terrace lengths bear a direct relationship to outlet design. When vegetative outlets are used, the area draining into the outlet must be in balance with outlet capacity established for the design slope and type



------ 0.4 Grade staked on surface
_____ 0.5 Excavation below_____
—·—·— Turned down to feather out to surface and also maintain 0.4' grade plus 0.2' in last 100' to clear trash.

STAKING A TERRACE OUTLET

Figure 4.3

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Graded Terraces (cont'd)

of vegetative cover. Outlet capacity is an important factor in determining terrace lengths. In general, 1,800 to 2,000 feet is the maximum distance that a terrace should drain water in one direction. Whenever terraces are in excess of 2,000 feet in length, the cross section shall be increased proportionately. When properly constructed and maintained, one-half mile terraces will give satisfactory service on permeable soils provided slopes are reasonably uniform. On badly gullied land a length of 1,200 feet should seldom be exceeded.

Level Terraces. Level terraces fall into two general categories. Those built for the primary purpose of providing supplemental moisture and those built primarily as an erosion control measure on permeable soils where the additional moisture will not be detrimental or where adequate outlets are not available for the use of graded terraces.

Level terraces are constructed without grade and may be built with ends closed, partially closed, or left open for drainage.

Whenever the ends of level terraces are left open, outlets should be provided.

Theoretically there is no limit to the length of a level terrace. In actual practice due to lack of control in construction, the elevation of the terrace may vary causing a flow of water toward the low spots which will overload the low section and may cause failure. Level terraces should be partially blocked every 3,000-3,500 feet as a safety measure. Level terraces must be carefully checked for low spots and the ridges strengthened where gullies are crossed.

Location of the Terrace Outlets

Factors to Consider. One of the most important factors in the successful operation of a terracing system is the location and design of the terrace outlet channels. The location of the outlets will depend primarily upon topographical features, types of outlets to be used, and the effect of the location on the convenience of carrying out farming operations.

A terrace system consisting of short terraces and several outlets located in natural watercourses is to be preferred to a system having long terraces and one outlet. The costs of outlets will be increased, but maintenance costs will be less. In general, the systems of short terraces will operate more satisfactorily than the long ones.

Natural watercourses are generally preferable to artificial field side outlets that do not follow natural drainage patterns. Natural watercourses should be used to the fullest extent possible as the location of terrace outlets and grassed waterways.

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Factors to Consider (cont'd)

The selected outlets should be checked for stability based on peak flood flow of 10-year frequency. Then the terracing system should be developed around them in such a way as to conform to the topography and yet use the outlets to best advantage.

If the field to be terraced receives any appreciable amount of runoff from an adjacent area, plans must be considered to divert the runoff from the terrace system by some form of diversion or interception ditch.

Pastures and Meadows. Well-sodded pastures and meadows provide good outlets.

The positions of terrace ends are often staggered onto meadows or pastures in order to prevent a concentration of water in volumes large enough to create gullies. See Figure 4.2. Under certain conditions it may be advisable to seed one end of a field to meadow rather than build a defined channel due to the nature of topography. The area converted to meadow should be large enough to safely disperse the water carried by the terraces and of a size to make haying operations worth while.

If desirable to provide a stable spoil area, the terrace ends may be tabled. That is, the outlet is flared to provide a level section at the end 6 to 10 feet wide to spread the water and cause it to flow from the table in a thin sheet preventing the concentration of flow and the forming of small gullies.

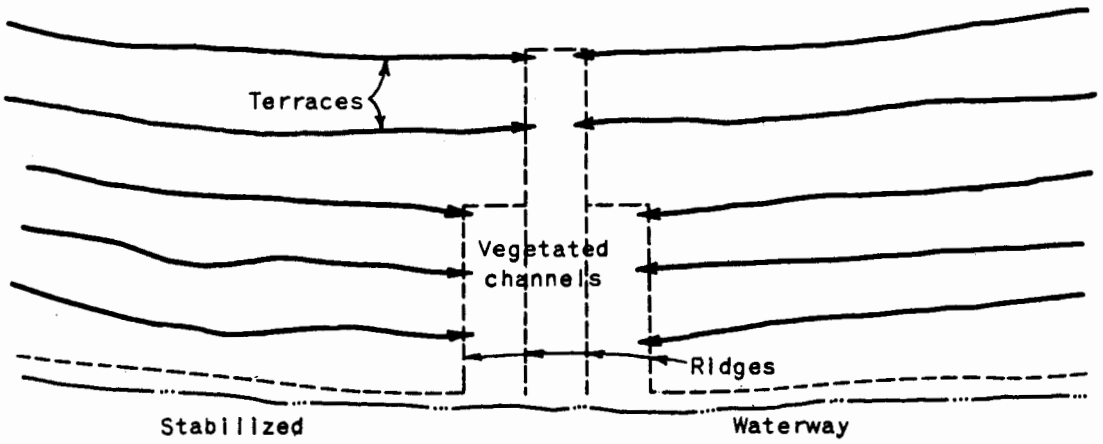
Care should be used in outletting terraces onto pastures so that concentrations of water will not flow into cattle trails, gullies, or bare erodible surfaces thus producing active gullies.

In some instances it is necessary to fence the outlet areas and exclude grazing.

Natural Waterways. Natural drainageways have advantages as terrace outlets. They are less apt to clog with silt and debris. The slope of a natural waterway is usually less than any other part of a field.

It is usually necessary to shape a natural waterway to a desired cross section. The amount of grading involved may run from a light surface smoothing to the filling of a sharp gully.

In the shaping of waterways, careful attention should be given to the placing of fertile soil on the surface for the support of an adequate grass cover.

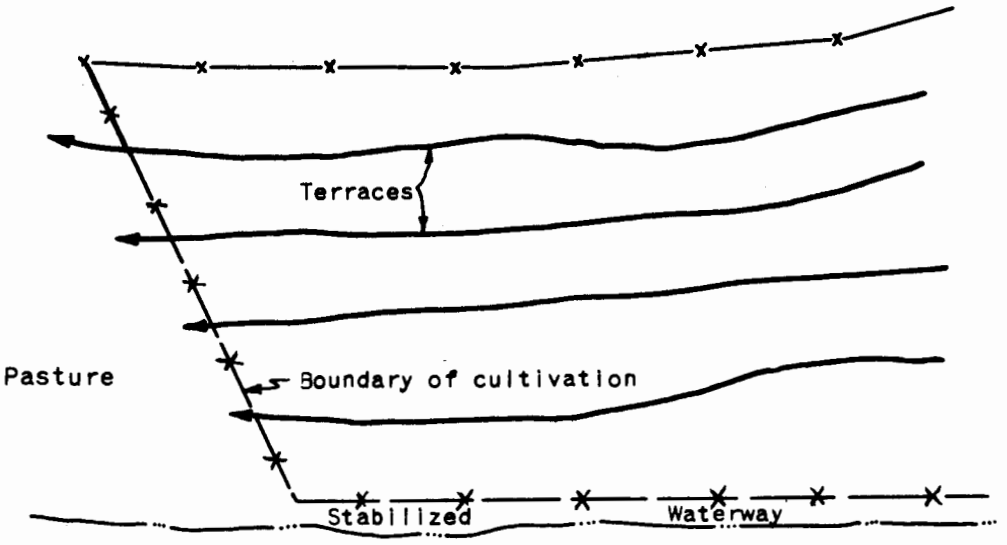


PLAN VIEW

CROSS SECTION

Ridges separating channels are low and well rounded to permit haying operations over area. Outside ridges should be higher than dividing ridges.

MULTIPLE CHANNEL OUTLET

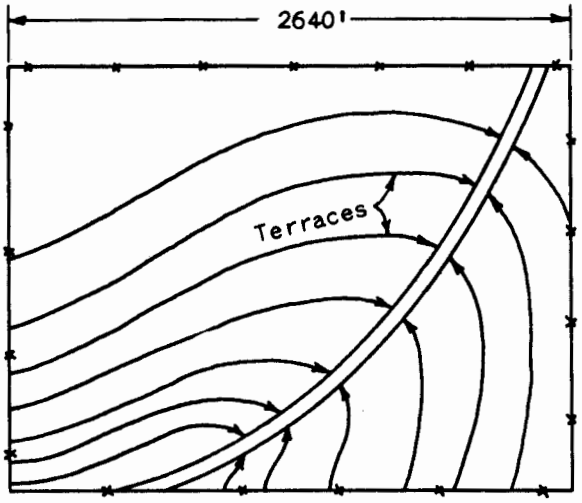


Outlets of terraces staggered so that runoff will not concentrate water in one channel.

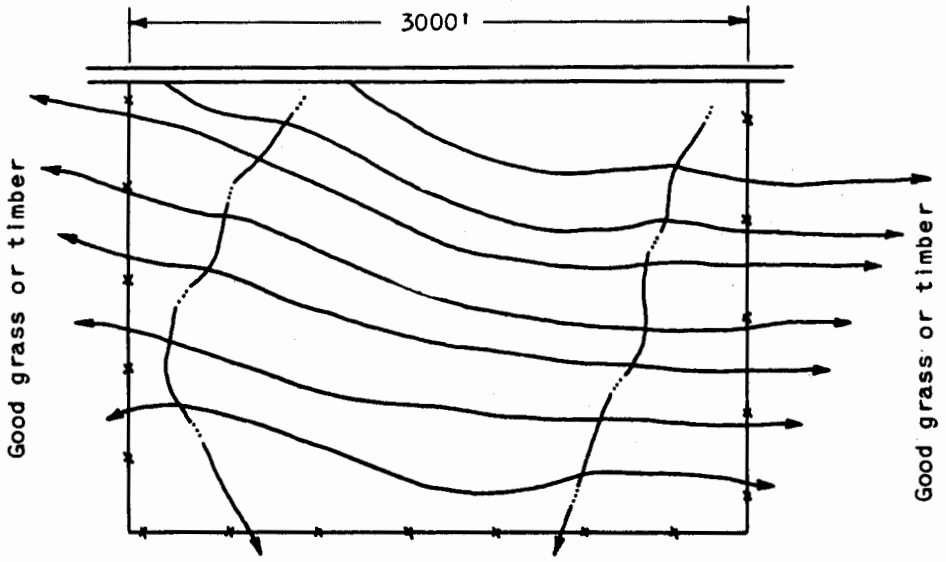
SEEDED MEADOW OUTLET

Figure 4.2

TYPICAL TERRACE OUTLETS



SEEDED OR SODDED OUTLET
IN NATURAL WATERWAY



TERRACES EXTENDED TO PREVENT
THE FORMATION OF GULLIES

Figure 4.3

METHODS OF WATER DISPOSAL

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Natural Waterways (cont'd)

Wet soils can be made suitable for the growth of desirable upland grasses by proper drainage. Where drainage is impracticable, grasses which grow on wet sites may be used.

In the construction of outlet channels, terrace waters should be excluded where feasible until a sufficient grass cover has been established. This may be accomplished by the use of temporary waterways or side ditches. Cutting in the temporary channels may be lessened by the use of close growing crops.

Side Field Cuts of Constructed Channels. Vegetated channels can be built at the sides of fields to serve for terrace outlets; however, they have several disadvantages. Excessive slopes are often encountered in such locations and generally along fence rows the ground is higher than the field elevation. This requires excessive cutting if terraces are to approach the fence line without abrupt downslope bends. Topsoil is usually stripped in the process of construction and this reduces the soil fertility. Silting difficulties often occur when water makes an abrupt turn at the ends of terraces. Side channels are subject to filling with silt caused by wind erosion.

Structural Terrace Outlets. Where vegetative terrace outlets will not suffice, it is necessary to build structures. Examples of the need of structures occur where:

1. Water must be dropped into a deep channel.
2. Velocities are too great to be borne by grass cover.
3. Grass cover cannot be established.

Structures are discussed in Part 15 and shown in SCS Engineering Standard Plans.

Roads and Lanes. It is very important that all farm and field access roads and lanes be carefully planned. Farm access roads may be placed on or just below a terrace ridge. In some cases the farm or field access road system may be placed on a natural ridge line or near the middle of the field where terraces are graded in each direction. In other instances the farm road or lane can be located on one side of the field so that it will cross on the closures at the closed ends of the terraces. Most important is the prevention or control of erosion along the travel routes over the farm. The ease with which farm equipment, seed, fertilizer, and harvested crops can be moved to or from the terraced field also is very important. Runoff water disposal areas should never be used for farm roads or lanes due to the erosion hazard.

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Cross Section Requirements

Terrace Cross Sections. The main requirements of satisfactory terrace cross sections are that they have:

(1) Channel and ridge side slopes long enough to fit the equipment to be used and to permit the operation of the available farm machinery along the terrace without undue damage to the terrace ridge and flat enough to permit practical operation of farm equipment.
(2) Ample channel capacity to handle the expected runoff.

The ease of farming increases when side slopes are flattened. However, the cost of construction likewise increases. For practical operation of farm equipment, side slopes of the channel or ridge should seldom be steeper than 5:1 with gentler side slopes being preferable. As the ground slope increases, it becomes more difficult to construct a terrace with farmable side slopes and the terraces become more closely spaced. It is, therefore, necessary to modify the cross section, permitting the use of steeper side slopes. The steeper limits for terrace side slopes are generally accepted as 5:1 for row crops, 4:1 for drill crops, and 3:1 for broadcast grass seedings.

The length of the slope should be such that it will fit the least flexible farm equipment that is to be used.

The design requirements of terraces for pasture land are the same as for cultivated land. However, they are not subject to the travel of farm equipment and need not have farmable side slopes. They may be as steep as the seeding equipment will permit for a good job of seeding.

Terraces shall have sufficient capacity to handle the peak runoff expected from a 10-year frequency storm without overtopping. The following table gives the volume of runoff for a given number of inches of runoff for various terrace spacings:

VOLUME OF RUNOFF IN
CUBIC FEET PER LINEAR FOOT

Horiz. Spacing	Runoff Inches 0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2
75	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.5	13.8
80	2.7	4.0	5.3	6.7	8.0	9.3	10.7	12.0	13.3	14.7
85	2.8	4.2	5.7	7.1	8.5	9.9	11.4	12.8	14.2	15.6
90	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5
100	3.3	5.0	6.6	8.3	10.0	11.6	13.2	15.0	16.7	18.3
120	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0
140	4.7	7.0	9.3	11.7	14.0	16.3	18.6	21.0	23.3	25.7
160	5.3	8.0	10.6	13.3	16.0	18.6	21.2	24.0	26.7	29.3
180	6.0	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0
200	6.7	10.0	13.3	16.7	20.0	23.3	26.6	30.0	33.3	36.7

Figure 4.4

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Terrace Cross Sections (cont'd)

Generally terraces should be built to contain the above volumes of runoff as time of concentration at the outlet is so long that the maximum volume reaches the terrace ridge before appreciable quantities are discharged at the outlet.

National requirements are that channel cross-section area be at least 6 sq. ft. for slopes over 8%, 7 sq. ft. for slopes 5 to 7%, and 8 sq. ft. for slopes of less than 5%.

Terrace Intervals

Using Terrace Spacing Formula. Terrace spacing may be determined by the formula VI = XS + Y where "S" is land slope in percent, "Y" is a soil and cropping factor, and "X" is a rainfall factor. "Y" is determined as follows:

Y = 1.0 for soils with below average intake rates and cropping systems that provide little cover during intense rainfall periods.

Y = 2.0 for soils with average or above intake rates and cropping systems that provide good cover during periods of intense rainfall.

Y = 1.5 where one of the above factors is favorable and the other unfavorable for soil intake.

"X" is a variable which is determined by location. It is largely dependent upon the quantity and intensity of precipitation. (For level terraces "X" = 0.8) For gradient terraces, see attached map for value for any specific location. (Figure 4.5)

Using Universal Soil Loss Equation. The Universal Soil Loss Equation may be used to determine terrace spacing. This formula is E = KRLSCP which, when used for terrace spacing determination, becomes SL = E/KRCP where:

L = Slope length factor.
S = Land slope factor.
E = Allowable soil loss in tons per acre per year. This may vary from 3 to 6 depending on the depth, texture, and erosion of the soil.
K = Soil intake factor which may vary from .15 to .49 depending on the intake characteristics of the soil profile.
R = Rainfall erosion factor. This will vary from a value of 50 in the northwest part of Nebraska to 250 along the south border of Missouri.
C = Cropping management factor which varies greatly according to the cropping system used.
P = Mechanical practice factor which varies as follows:

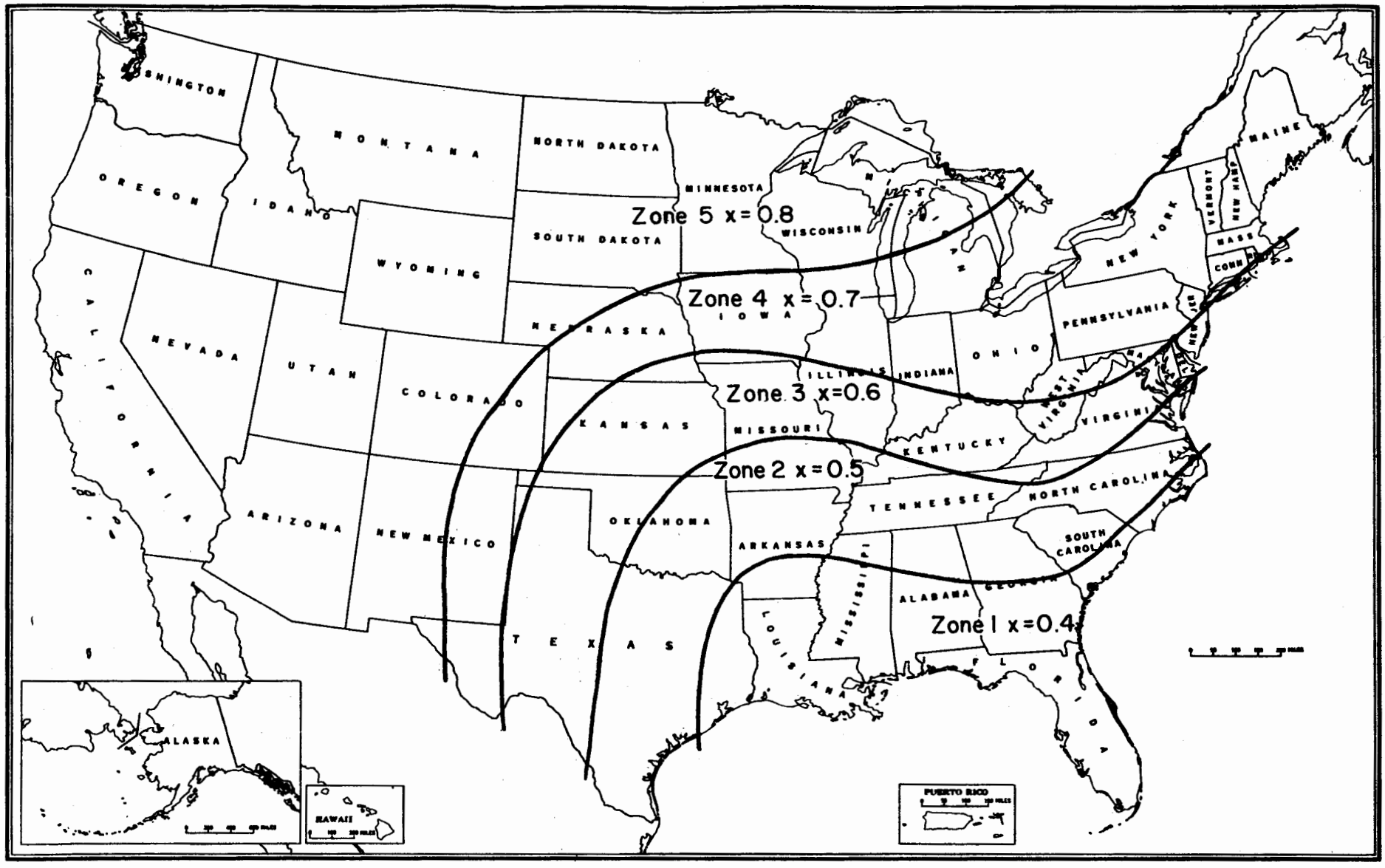


Figure 4.5

Values of x in equation V.I=xs+y

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Using Universal Soil Loss Equation (cont'd)

"P" factor for various land slopes

Percent Slope	Lister Planting	Surface Planting
1.1 - 2.0	.45	.60
2.1 - 7.0	.38	.50
7.1 - 12.0	.45	.60
12.1 - 18.0	.60	.80
18.1 - 24.0	.68	.90

To show how the Universal Soil Loss Equation may be used to determine terrace spacing, use the following sample problem and solution:

Problem: Determine terrace spacing for a 7% slope on a Marshall Silt Loam Soil located in the northeast corner of Kansas. Two possibilities of cropping systems are being considered:
(1) 5-year rotation of corn, oats, wheat with sweet clover, sweet clover.
(2) 4-year rotation of corn, oats, wheat with sweet clover, sweet clover.

Solution: (1) 2-year lister planting, 3 years surface planting - P = .45
(2) 1-year lister planting, 3 years surface planting - P = .47

"E" for Marshall Silt Loam = 5.0
"K" for Marshall Silt Loam = .32
"R" for northeast Kansas = 190
"C" for rotation (1) = .24
"C" for rotation (2) = .16

(1) Then SL = 5 + .32 x 190 x .24 x .45 (first rotation)
(2) And SL = 5 + .32 x 190 x .16 x .47 (second rotation)
(1) Then SL = .76
(2) SL = 1.09
*(1) L_p for 7% slope when SL = .76 is 90 feet (approximately)
*(2) L_p for 7% slope when SL = 1.09 is 175 feet (approximately)

*Formula to calculate "Lp" when SL has been determined:

$$SL = \frac{\sqrt{Lp}}{100}\left(0.76 + 0.53S_i + 0.076S_i^2\right) \text{ or}$$

$$Lp = \left[\frac{100SL}{0.76 + 0.53S_i + 0.076S_i^2}\right]^2$$

Where "S_i" is land slope in percent.
Lp is horizontal terrace spacing in feet.

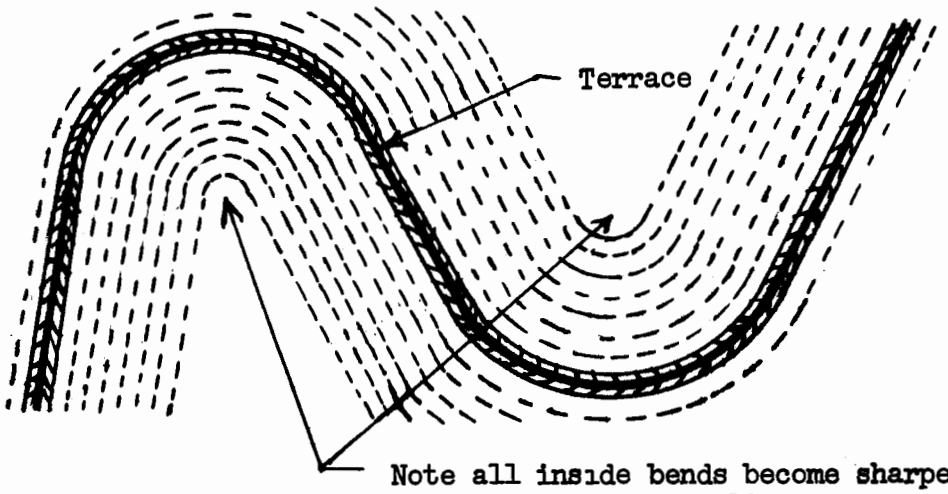
4. LAYOUT OF TERRACE SYSTEM

General

The layout of terrace systems in many cases has consisted of merely determining the spacing from a formula, selecting an allowable grade, and then mechanically staking the terrace line. The importance that terraces play in both erosion control and moisture conservation justifies far more attention to the layout than this mere mechanical operation. When terraces are constructed, it is expected that they will be a permanent part of the farm for the next 20 to 30 years and that with the help of other conservation practices soil losses will be held to a minimum.

In the layout of terraces there are five things which should receive careful attention to assure that the system will be as practical to farm as the physical conditions of the field will permit. These are (1) sharp bends in the terrace lines, (2) approaching obstacles at acute angles, (3) unnecessary point rows, (4) crossing narrow ridges with terraces, and (5) adequacy of outlets.

(1) Sharp bends are difficult to make with modern farm equipment. They are especially troublesome wherever farm equipment must turn inside the bend because they become sharper as farming operations proceed away from the terrace line.



AVOIDING SHARP BENDS
Figure 4.6

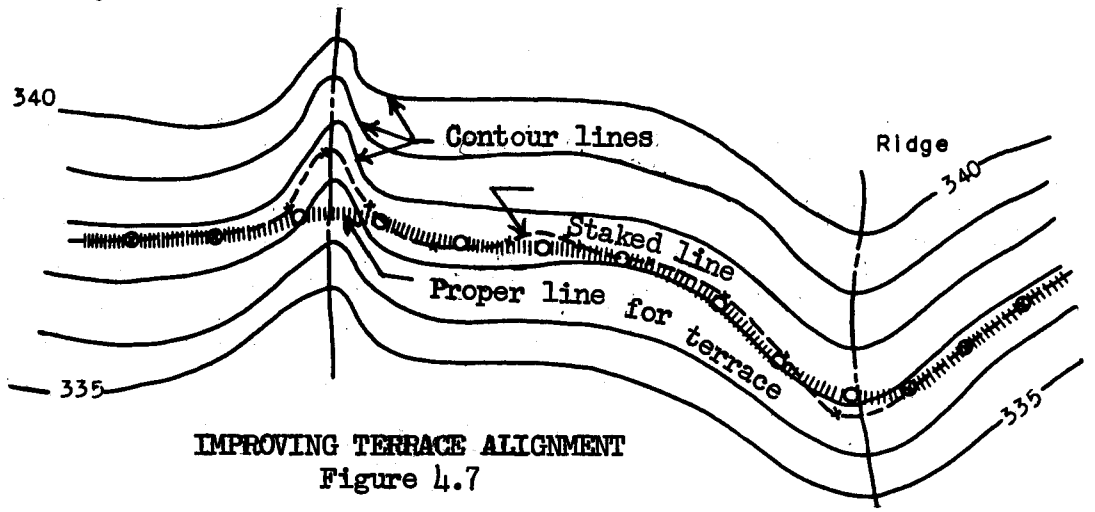
4. LAYOUT OF TERRACE SYSTEM (CONT'D)

General (cont'd)

(2) Approaching obstacles at an acute angle make farming operations very difficult as this results in sharp corners where it is virtually impossible to turn farm equipment. Terrace lines approaching narrow drains tend to turn up rather abruptly. If these drains are used as waterways, the terrace ends can be lowered sufficiently to provide good terrace drainage and also to eliminate the sharp angles. Farming operations or soil blowing frequently have caused field boundaries to be higher than the adjacent field. In such cases the terrace lines would turn rather abruptly down the boundary line. To prevent this, the terraces can be blocked if an adequate outlet is provided at the other end. If terraces must spill at this end, the high area along the boundary can be left as a road and the terraces ended before reaching the high area and a waterway provided between the terrace and the farm road.

(3) Unnecessary point rows are one of the main reasons that farmers retire terraced fields from cultivation.

If terraces are to be maintained and serve their intended purpose for several years, they must fit into an economical farming operation. To best do this, it is imperative that as many point rows be eliminated as is practical. Terrace layout, therefore, becomes an engineering planning and design procedure rather than a mechanical line running process.



IMPROVING TERRACE ALIGNMENT
Figure 4.7

A great deal can be done with both level and graded terraces to make them more nearly parallel. Point rows can be eliminated in level terrace systems by making line adjustments with cuts and fills along the terrace lines. Level terrace systems where groups of terraces can be made parallel are limited to uniform fairly flat slopes, but many point rows can be eliminated in nearly any system. Point rows can be eliminated in gradient terrace systems by both changes in grade and by cuts and fills along the terrace lines.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

General (cont'd)

(4) When terrace lines cross narrow ridges, they generally require sharp bends. If adequate outlets are provided in the natural drains, the terraces can end on each side of the ridge. When this is done, the ridges provide excellent field roads and help to keep the farm waterways from being used as farm roads.

(5) A common practice is to provide terrace outlets at the field boundaries and to cross the natural drains with the terrace ridges. Field boundaries generally have steeper slopes, poorer soils, and shapes less suited for waterway use than do the natural watercourses. It is normally best to use the same locations for waterways that nature has provided to dispose of excess water. An adequate number of outlets should be provided. The greater the number of outlets that are provided, the more can be done to make the terrace system more farmable.

The Key Terrace

As a general rule, the upper terrace is staked first and each succeeding terrace staked in turn. An exception to this rule may be made if it is desired to have a definite location for some particular terrace in the system. This terrace would then be located first and a sufficient number of terraces staked between it and the drainage divide to insure that the maximum vertical interval for any one terrace would not be exceeded.

The location and construction of the top terrace is very important. If the top terrace fails, it often causes the failure of the lower terraces.

Some general rules for location of the top terrace are:

If the top of the hill comes to a point, the interval may be increased to one and one-half times the regular terrace interval.

On sharp sloping ridges, the interval may be increased to one and one-fourth times the regular terrace interval.

On long ridges where the terrace approximately parallels the ridge, the regular interval should be used.

The watershed area above the top terrace should not exceed the area obtained by multiplying the terrace length by the normal terrace spacing for the slope and soil above the top terrace.

Staking the Graded Terrace Outlet

A method of staking a terrace outlet is shown in Figure 4.1. A drop of 1.1 feet is given the last 100 feet. Of this amount, 0.4 feet is the

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

Staking the Graded Terrace Outlet (cont'd)

continuation of the 0.4% slope, 0.5 feet is allowed for the depth of channel excavation, and 0.2 feet is given to clear trash and silt. If a drop of 0.5 feet is not allowed for the depth of channel excavation, the grade of the channel will rise in the last one hundred feet and the cross section of the channel at Station 13+00 will be restricted. The need for a drop of 0.2 feet to clear trash depends upon local conditions.

Since the longitudinal section of the channel excavation feathers out as the channel grade meets the grade of the outlet, there will not be enough dirt available from the channel excavation to build the terrace ridge. Earth to make the fill can be had by deepening the channel with the expectation that the pit will silt up in time or the fill can be made by borrowing material elsewhere. The photograph in Figure 4.1 gives another illustration of the principles involved in staking the outlet of a terrace.

Determining the Vertical Interval

On fairly uniform slopes the average slope of the area can be used in computing the vertical interval for the terraces. If the slopes vary considerably, the weighted average of all the slopes that a terrace is to cross should be used in computing the vertical terrace interval for each terrace. On some fields it may be advisable to reduce or increase the indicated interval for certain terraces in the system in order to place them advantageously. It may also be necessary to make adjustments between terrace intervals for graded terraces in order to get proper alignment at the outlet. Very frequently special consideration must be given to factors other than vertical interval alone in determining the location of the top terrace of a system due to the peculiar shape and direction of slope of the top portion of the area to be terraced. There may be an abrupt change in slope on some part of a field. It may be necessary to place the terrace either just above or just below the slope. This becomes a key terrace and others are placed in proper relation to it.

For graded terraces, it is usually found most convenient to start staking at the outlet end particularly if there are terraces discharging into both sides of the outlet so that proper alignment is attained. Stakes should be set at 50-foot intervals except on curves and through draws where a 25-foot spacing should be used. Where topography is uniform, 100-foot and 50-foot spacing, respectively, may be satisfactory.

It is not always possible to secure the most satisfactory terrace layout in the first attempt. After a few lines have been staked, topographical features will sometimes be encountered that will favor changes in terrace lines. If such changes are extensive, it is usually best to pull up all stakes and start over again.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

Determining the Vertical Interval (cont'd)

After the terrace lines have been staked, some realignment is necessary on each proposed terrace in order to eliminate undesirable sharp curves, to obtain greater ease of construction, and to secure a finished terrace that will offer a minimum of inconvenience in later tillage operations. The general procedure is illustrated in Figure 4.7. The movement of terrace lines up and down slopes will, of necessity, be restricted by the drainage and construction features encountered. Usually the straightening should be limited in upward movement so that not more than a 6-inch additional cut will be necessary in the terrace channel and the number of cuts of this depth should be kept to a minimum. The straightening of terraces through depressions should not be such as will introduce excessive ridge heights and objectionable pond areas.

Relation of the Staked Line to the Completed Terrace

Graded Terrace. The channel is constructed on the stake line to make the constructed channel grade the same as the designed grade. Additional depth of channel cuts is made to compensate for any uphill adjustment of the stake line of ridges. Additional height of ridge fill is made across gullies, narrow depressions, or lows resulting from any downhill adjustment of the stake line.

Level Terrace. The ridge is built on the surveyed stake line to make the constructed ridge a level impounding levee. Fills are made in low spots to make the settled ridge top level.

Adjustments to Improve Terrace Alignment

Figure 4.8 shows a topographic map with contours taken in the field at 5-foot vertical intervals and interpolated at 1-foot intervals on the map. The 1-foot contours are shown in dotted lines. The lines with arrows show scaled slopes.

A system of terraces has been plotted on this map beginning with the top terrace and proceeding down the slope.

The stippling shows the areas of variable width between the terraces. These irregular areas cause point rows which increase the number of turns required in cultivation and add to the cost of farming. If, by care in planning, point rows can be eliminated or reduced, the cost of cultivation can be reduced.

It is desirable sometimes to use greater refinement in the design of terrace systems to eliminate point rows or otherwise improve the system than can readily be obtained by field observation. For this purpose, topographic maps are particularly useful.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

Paralleling Terraces

In laying out terraces, it is frequently possible to make a pair of terraces parallel throughout or in part and thus reduce the number of point rows in a field.

In view of the time and effort saved for the farmer over a period of years if a set of point rows is eliminated, the technician is justified in spending several hours, if necessary, to accomplish this.

If several of the natural drains are used as waterways the paralleling of terraces is more readily accomplished.

The maximum spacing of parallel terraces should be in accordance with the spacing criteria for standard terraces. The use of parallel terraces eliminates to a great extent the objection to narrow spacing as turning within the field is eliminated. Spacing used should be within the above maximum but should be adjusted to fit complete trips of least flexible farm equipment that will be used.

The amount that terrace lines can be moved for terrace alignment is dependent on the maximum allowable grade and on the permissible cut to be made. For level terraces, the maximum permissible cut would govern.

Two systems for the layout of parallel terrace systems are recommended. Which one is used is dependent on the uniformity of the slopes to be terraced.

System 1 - Uniform Slopes. Beginning at the highest part of the field, the slope should be measured to approximately the center of the field in sufficient detail to determine the number of and general location of terraces.

Then the key terrace should be staked to grade. This key terrace will usually be located about midway down the slope. Sharp bends and minor irregularities should be corrected on this terrace line and the line marked out by use of farm tractor or other positive means of line marking. Using a small rope or similar measuring device, stake two terrace lines parallel to this terrace on the selected vertical interval and horizontal spacing, one on each side of the key terrace. One man will walk along the key terrace and make sure the rope is perpendicular to the line as the second man marks the adjoining parallel lines. The final location of the line is best made by use of the farm equipment with a spacing marker to assure that spacing is kept uniform on curves. The final line is then checked to determine if it meets layout requirements.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

System 1 - Uniform Slopes (cont'd)

Additional parallel terrace lines are run in the same manner until the allowable grade plus maximum determined cut is exceeded. When this is the case, another series of terraces are laid out in the same manner. To determine when a new series of terraces must be started, rod readings or elevations should be taken on the staked lines. These readings are plotted on profile paper and lines drawn that will balance cut and fill. These lines must be within the allowable grade.

System 2 - Irregular Slopes. For irregular slopes, the entire set of terraces is staked out as for conventional terraces. Key terraces are then selected that best fit in with terraces on both sides. Short sharp bends and minor irregularities are then corrected on the key terraces, a number of measurements made between the key terrace and adjoining terrace to determine the average horizontal spacing that will fit the farm equipment to be used, and the adjoining terraces made parallel to the key terrace in the same manner as in System 1. In some cases only sections of the terraces can be paralleled but even partial paralleling can result in considerable reduction of the number of point rows.

An alternate system that makes use of a grid survey is an excellent method of laying out terraces. A grid map on 100-foot centers is made of the field to be terraced. Terraces can then be planned on the grid map and transferred directly to the field by measuring the lines in from the grid points. This method may require somewhat more time than the others but generally results in a better terrace layout as location of key terraces is easier to determine and allowable alteration of terrace lines can readily be made.

If paralleling is accomplished to the point that cut and fill terraces are to be made, it will be necessary to obtain elevation readings at each stake line on the parallel lines. For uniformity of construction, the stake line is usually at the intersection of the terrace ridge front slope and the terrace channel.

If paralleled terraces are to be constructed with motor grader, bulldozer or similar equipment, the ground along the terrace line will need to be brought to the elevation of the grade line. If the terraces are to be constructed with carry-all type equipment, then the terrace channel and ridge will be shaped as excavation and fill are made. This will eliminate the need of moving the ridge portion of the terrace where this portion is above the average ground line but not above the top of the terrace ridge.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

System 2 - Irregular Slopes (cont'd)

Figure 4.9 shows a revised layout of the terrace system shown in Figure 4.8. In the revision, terraces have been made to lie more nearly parallel to each other and thus reduce the number and size of irregular areas. An inspection of the two layouts will show the amount of this reduction. To accomplish this result, the positions of the terraces have been altered by changing the location of summits which in turn have changed the total fall of the terraces. Grades have been steepened at the upper ends of terraces (summits) where the volume of water carried by the terrace is small. Thus, it has been possible to make terraces 1, 2, and 3 parallel to each other and eliminate irregular areas between them. In laying the lines in the field, terrace 2 would be staked according to grade elevations shown and terraces 1 and 3 would be placed by measuring uniform distances from terrace 2. Grade elevations would be checked for terraces 1 and 3 to insure an acceptable grade line. Terraces 3 and 4 have been made partially parallel to each other by varying the grades on terrace 4. Part of terrace 4 has a variable grade as shown and part of it has a uniform grade of 0.5 feet per 100 feet. In this way, the size of the irregular area between these two terraces has been reduced.

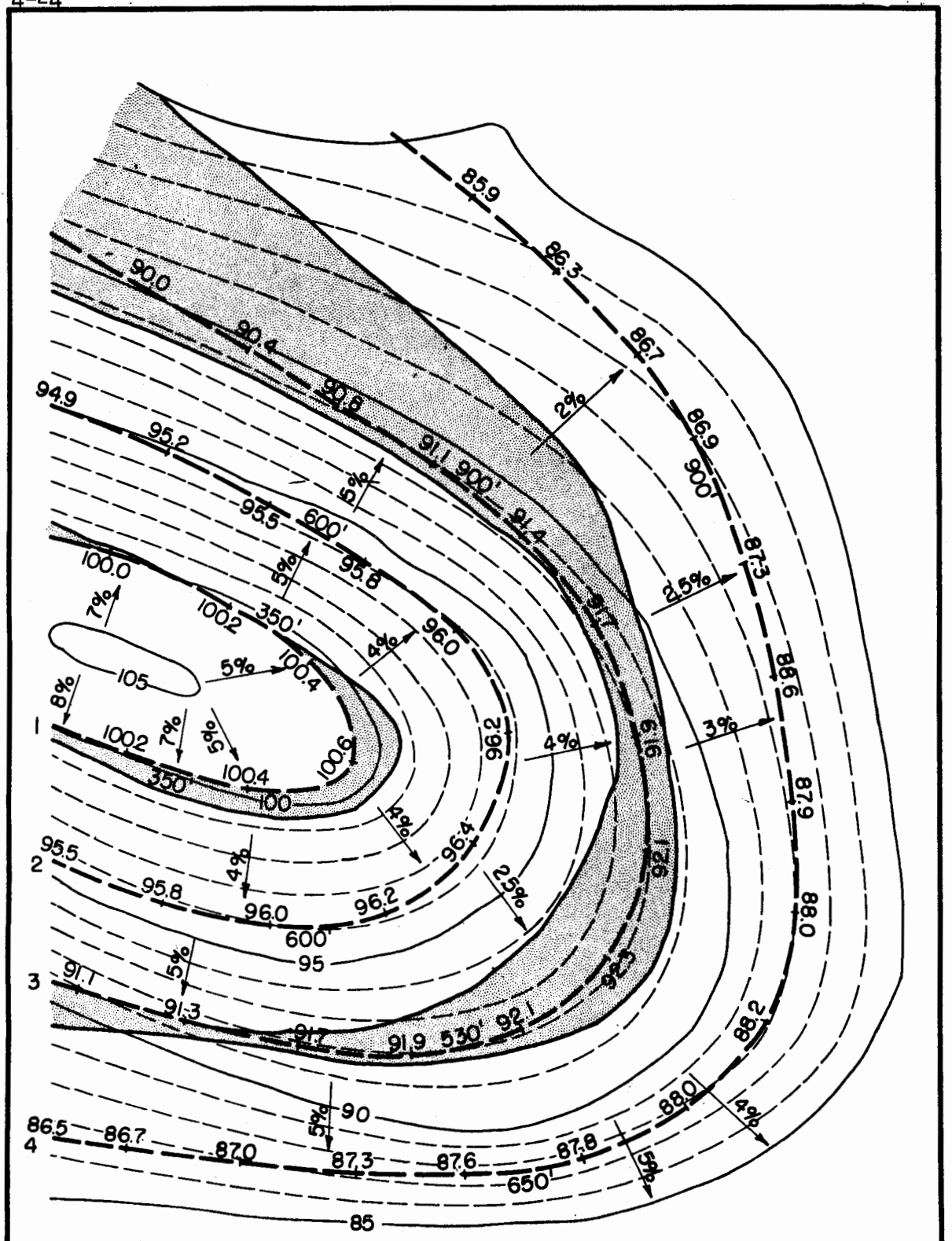
It will be seen that terrace layout 2 can be farmed more easily than terrace layout 1.

In areas where soils are permeable and slopes are uniform, considerable paralleling of terraces has been done to advantage.

In areas where soils are impervious and slopes are irregular, it is difficult to parallel terraces without causing objectionable ponding.

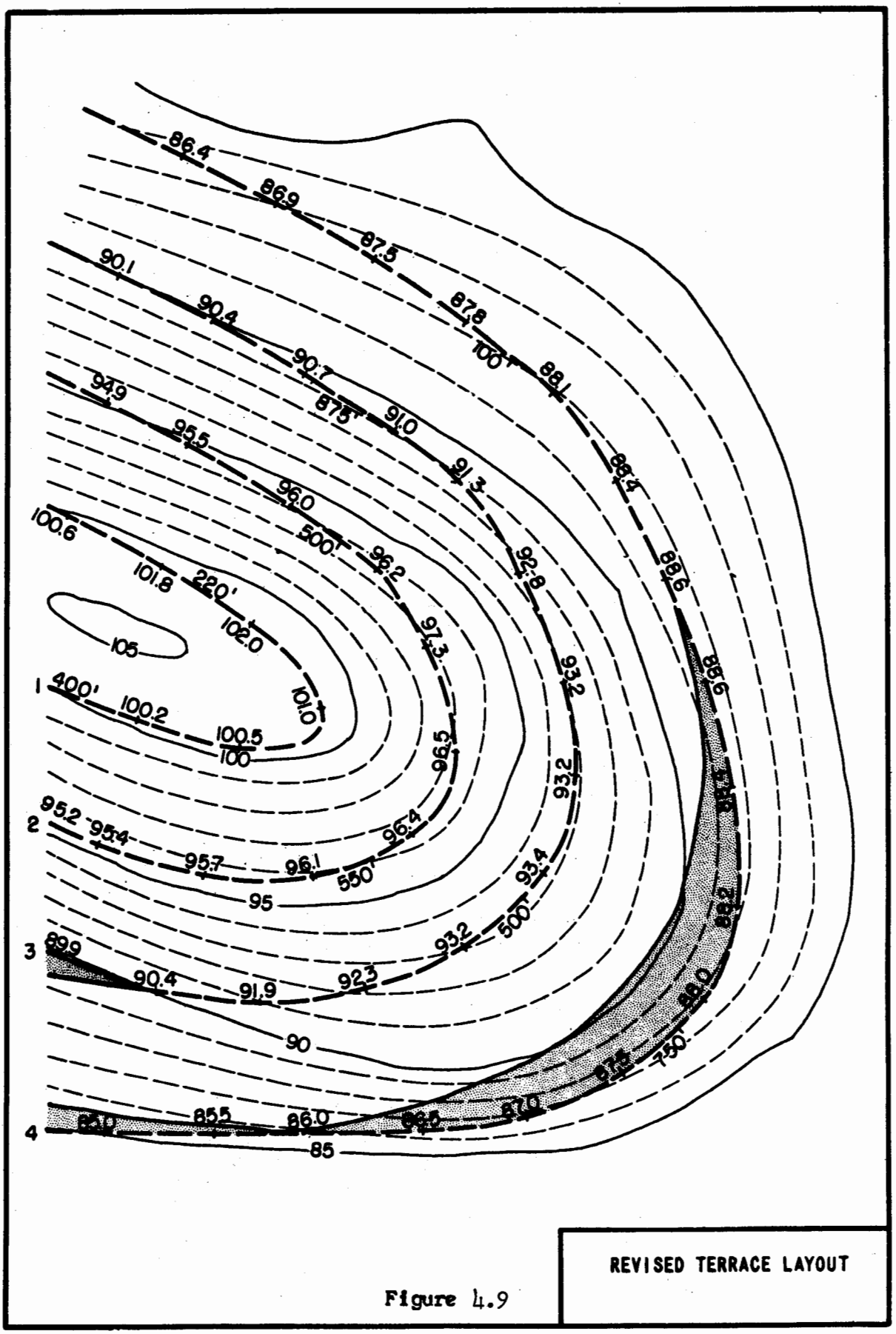
In attempts to make lands between terraces uniform in width, care should be used to avoid excessive cuts and fills. While soil types will influence the limits, in general, cuts should not exceed one-half foot below the usual terrace channel and fills should not exceed moderate heights.

Also, terrace grades should be sufficient to provide proper drainage, but they should not be so steep as to cause erosion in the terrace channels and the washing out of crops.



TERRACE LAYOUT

Figure 4.8



REVISED TERRACE LAYOUT

Figure 4.9

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

System 2 - Irregular Slopes (cont'd)

On large fields it is seldom possible to parallel the terraces over an entire field. More often it is possible to parallel groups of terraces or portions of groups where slopes are regular.

Staking Cuts or Fills Where Alignment is Improved

If the terrace as finally laid out varies from the planned grade line by more than approximately 0.2 foot, it will be necessary to set cut and fill stakes to guide the equipment operator in installing the structure. If the variation is only for short segments through narrow ridges or across narrow drains, cuts and fills can readily be determined from the original line survey.

When the terrace line varies from the planned grade line for an appreciable portion of the total length, it is generally advisable to profile the entire line and then determine the extent of cuts and fills necessary.

Where the construction line is within the approximate 0.2 of the surveyed line, the equipment operator can normally construct the terrace without additional cut or fill stakes.

The technician planning or laying out the terrace system should keep in mind that every point row that can be eliminated will result in a saving in farming cost for a number of years. Even though only segments of terraces can be paralleled, this is much preferred over no paralleling at all.

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Graded Terraces (cont'd)

of vegetative cover. Outlet capacity is an important factor in determining terrace lengths. In general, 1,800 to 2,000 feet is the maximum distance that a terrace should drain water in one direction. Whenever terraces are in excess of 2,000 feet in length, the cross section shall be increased proportionately. When properly constructed and maintained, one-half mile terraces will give satisfactory service on permeable soils provided slopes are reasonably uniform. On badly gullied land a length of 1,200 feet should seldom be exceeded.

Level Terraces. Level terraces fall into two general categories. Those built for the primary purpose of providing supplemental moisture and those built primarily as an erosion control measure on permeable soils where the additional moisture will not be detrimental or where adequate outlets are not available for the use of graded terraces.

Level terraces are constructed without grade and may be built with ends closed, partially closed, or left open for drainage.

Whenever the ends of level terraces are left open, outlets should be provided.

Theoretically there is no limit to the length of a level terrace. In actual practice due to lack of control in construction, the elevation of the terrace may vary causing a flow of water toward the low spots which will overload the low section and may cause failure. Level terraces should be partially blocked every 3,000-3,500 feet as a safety measure. Level terraces must be carefully checked for low spots and the ridges strengthened where gullies are crossed.

Location of the Terrace Outlets

Factors to Consider. One of the most important factors in the successful operation of a terracing system is the location and design of the terrace outlet channels. The location of the outlets will depend primarily upon topographical features, types of outlets to be used, and the effect of the location on the convenience of carrying out farming operations.

A terrace system consisting of short terraces and several outlets located in natural watercourses is to be preferred to a system having long terraces and one outlet. The costs of outlets will be increased, but maintenance costs will be less. In general, the systems of short terraces will operate more satisfactorily than the long ones.

Natural watercourses are generally preferable to artificial field side outlets that do not follow natural drainage patterns. Natural watercourses should be used to the fullest extent possible as the location of terrace outlets and grassed waterways.

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Factors to Consider (cont'd)

The selected outlets should be checked for stability based on peak flood flow of 10-year frequency. Then the terracing system should be developed around them in such a way as to conform to the topography and yet use the outlets to best advantage.

If the field to be terraced receives any appreciable amount of runoff from an adjacent area, plans must be considered to divert the runoff from the terrace system by some form of diversion or interception ditch.

Pastures and Meadows. Well-sodded pastures and meadows provide good outlets.

The positions of terrace ends are often staggered onto meadows or pastures in order to prevent a concentration of water in volumes large enough to create gullies. See Figure 4.2. Under certain conditions it may be advisable to seed one end of a field to meadow rather than build a defined channel due to the nature of topography. The area converted to meadow should be large enough to safely disperse the water carried by the terraces and of a size to make haying operations worth while.

If desirable to provide a stable spoil area, the terrace ends may be tabled. That is, the outlet is flared to provide a level section at the end 6 to 10 feet wide to spread the water and cause it to flow from the table in a thin sheet preventing the concentration of flow and the forming of small gullies.

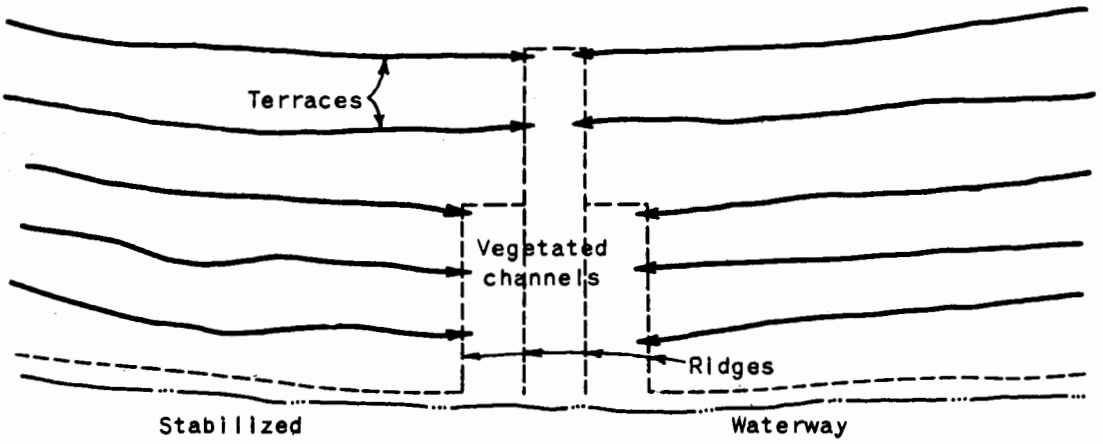
Care should be used in outletting terraces onto pastures so that concentrations of water will not flow into cattle trails, gullies, or bare erodible surfaces thus producing active gullies.

In some instances it is necessary to fence the outlet areas and exclude grazing.

Natural Waterways. Natural drainageways have advantages as terrace outlets. They are less apt to clog with silt and debris. The slope of a natural waterway is usually less than any other part of a field.

It is usually necessary to shape a natural waterway to a desired cross section. The amount of grading involved may run from a light surface smoothing to the filling of a sharp gully.

In the shaping of waterways, careful attention should be given to the placing of fertile soil on the surface for the support of an adequate grass cover.

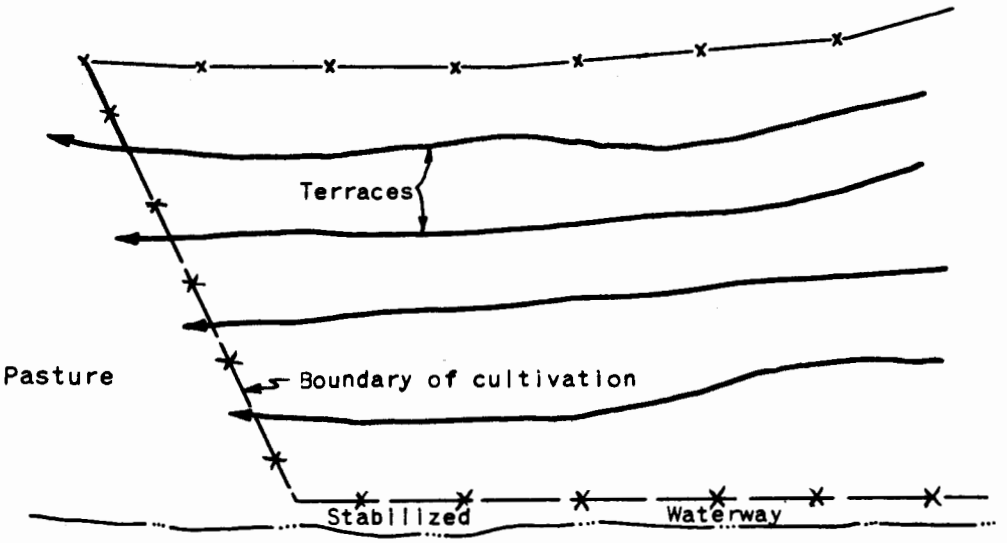


PLAN VIEW

CROSS SECTION

Ridges separating channels are low and well rounded to permit haying operations over area. Outside ridges should be higher than dividing ridges.

MULTIPLE CHANNEL OUTLET

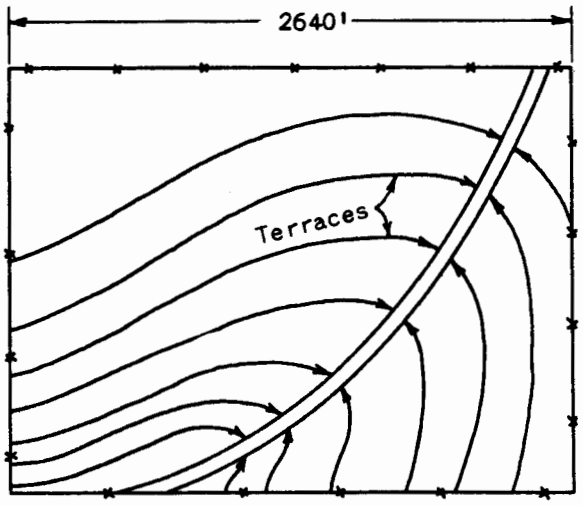


Outlets of terraces staggered so that runoff will not concentrate water in one channel.

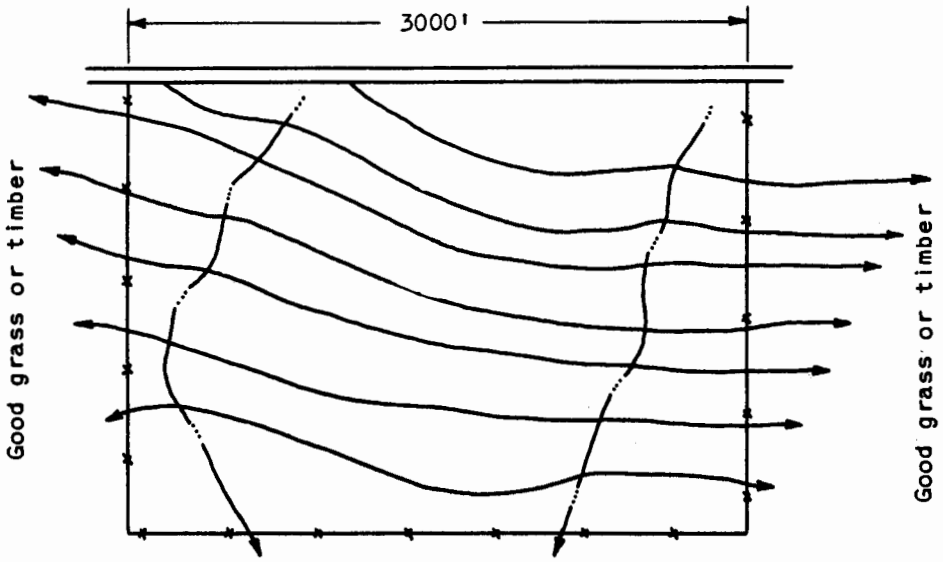
SEEDED MEADOW OUTLET

Figure 4.2

TYPICAL TERRACE OUTLETS



SEEDED OR SODDED OUTLET
IN NATURAL WATERWAY



TERRACES EXTENDED TO PREVENT
THE FORMATION OF GULLIES

Figure 4.3

METHODS OF WATER DISPOSAL

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Natural Waterways (cont'd)

Wet soils can be made suitable for the growth of desirable upland grasses by proper drainage. Where drainage is impracticable, grasses which grow on wet sites may be used.

In the construction of outlet channels, terrace waters should be excluded where feasible until a sufficient grass cover has been established. This may be accomplished by the use of temporary waterways or side ditches. Cutting in the temporary channels may be lessened by the use of close growing crops.

Side Field Cuts of Constructed Channels. Vegetated channels can be built at the sides of fields to serve for terrace outlets; however, they have several disadvantages. Excessive slopes are often encountered in such locations and generally along fence rows the ground is higher than the field elevation. This requires excessive cutting if terraces are to approach the fence line without abrupt downslope bends. Topsoil is usually stripped in the process of construction and this reduces the soil fertility. Silting difficulties often occur when water makes an abrupt turn at the ends of terraces. Side channels are subject to filling with silt caused by wind erosion.

Structural Terrace Outlets. Where vegetative terrace outlets will not suffice, it is necessary to build structures. Examples of the need of structures occur where:

1. Water must be dropped into a deep channel.
2. Velocities are too great to be borne by grass cover.
3. Grass cover cannot be established.

Structures are discussed in Part 15 and shown in SCS Engineering Standard Plans.

Roads and Lanes. It is very important that all farm and field access roads and lanes be carefully planned. Farm access roads may be placed on or just below a terrace ridge. In some cases the farm or field access road system may be placed on a natural ridge line or near the middle of the field where terraces are graded in each direction. In other instances the farm road or lane can be located on one side of the field so that it will cross on the closures at the closed ends of the terraces. Most important is the prevention or control of erosion along the travel routes over the farm. The ease with which farm equipment, seed, fertilizer, and harvested crops can be moved to or from the terraced field also is very important. Runoff water disposal areas should never be used for farm roads or lanes due to the erosion hazard.

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Cross Section Requirements

Terrace Cross Sections. The main requirements of satisfactory terrace cross sections are that they have:

(1) Channel and ridge side slopes long enough to fit the equipment to be used and to permit the operation of the available farm machinery along the terrace without undue damage to the terrace ridge and flat enough to permit practical operation of farm equipment.
(2) Ample channel capacity to handle the expected runoff.

The ease of farming increases when side slopes are flattened. However, the cost of construction likewise increases. For practical operation of farm equipment, side slopes of the channel or ridge should seldom be steeper than 5:1 with gentler side slopes being preferable. As the ground slope increases, it becomes more difficult to construct a terrace with farmable side slopes and the terraces become more closely spaced. It is, therefore, necessary to modify the cross section, permitting the use of steeper side slopes. The steeper limits for terrace side slopes are generally accepted as 5:1 for row crops, 4:1 for drill crops, and 3:1 for broadcast grass seedings.

The length of the slope should be such that it will fit the least flexible farm equipment that is to be used.

The design requirements of terraces for pasture land are the same as for cultivated land. However, they are not subject to the travel of farm equipment and need not have farmable side slopes. They may be as steep as the seeding equipment will permit for a good job of seeding.

Terraces shall have sufficient capacity to handle the peak runoff expected from a 10-year frequency storm without overtopping. The following table gives the volume of runoff for a given number of inches of runoff for various terrace spacings:

VOLUME OF RUNOFF IN
CUBIC FEET PER LINEAR FOOT

Horiz. Spacing	Runoff Inches 0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2
75	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.3	12.5	13.8
80	2.7	4.0	5.3	6.7	8.0	9.3	10.7	12.0	13.3	14.7
85	2.8	4.2	5.7	7.1	8.5	9.9	11.4	12.8	14.2	15.6
90	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5
100	3.3	5.0	6.6	8.3	10.0	11.6	13.2	15.0	16.7	18.3
120	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0
140	4.7	7.0	9.3	11.7	14.0	16.3	18.6	21.0	23.3	25.7
160	5.3	8.0	10.6	13.3	16.0	18.6	21.2	24.0	26.7	29.3
180	6.0	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0
200	6.7	10.0	13.3	16.7	20.0	23.3	26.6	30.0	33.3	36.7

Figure 4.4

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Terrace Cross Sections (cont'd)

Generally terraces should be built to contain the above volumes of runoff as time of concentration at the outlet is so long that the maximum volume reaches the terrace ridge before appreciable quantities are discharged at the outlet.

National requirements are that channel cross-section area be at least 6 sq. ft. for slopes over 8%, 7 sq. ft. for slopes 5 to 7%, and 8 sq. ft. for slopes of less than 5%.

Terrace Intervals

Using Terrace Spacing Formula. Terrace spacing may be determined by the formula VI = XS + Y where "S" is land slope in percent, "Y" is a soil and cropping factor, and "X" is a rainfall factor. "Y" is determined as follows:

Y = 1.0 for soils with below average intake rates and cropping systems that provide little cover during intense rainfall periods.

Y = 2.0 for soils with average or above intake rates and cropping systems that provide good cover during periods of intense rainfall.

Y = 1.5 where one of the above factors is favorable and the other unfavorable for soil intake.

"X" is a variable which is determined by location. It is largely dependent upon the quantity and intensity of precipitation. (For level terraces "X" = 0.8) For gradient terraces, see attached map for value for any specific location. (Figure 4.5)

Using Universal Soil Loss Equation. The Universal Soil Loss Equation may be used to determine terrace spacing. This formula is E = KRLSCP which, when used for terrace spacing determination, becomes SL = E/KRCP where:

L = Slope length factor.
S = Land slope factor.
E = Allowable soil loss in tons per acre per year. This may vary from 3 to 6 depending on the depth, texture, and erosion of the soil.
K = Soil intake factor which may vary from .15 to .49 depending on the intake characteristics of the soil profile.
R = Rainfall erosion factor. This will vary from a value of 50 in the northwest part of Nebraska to 250 along the south border of Missouri.
C = Cropping management factor which varies greatly according to the cropping system used.
P = Mechanical practice factor which varies as follows:

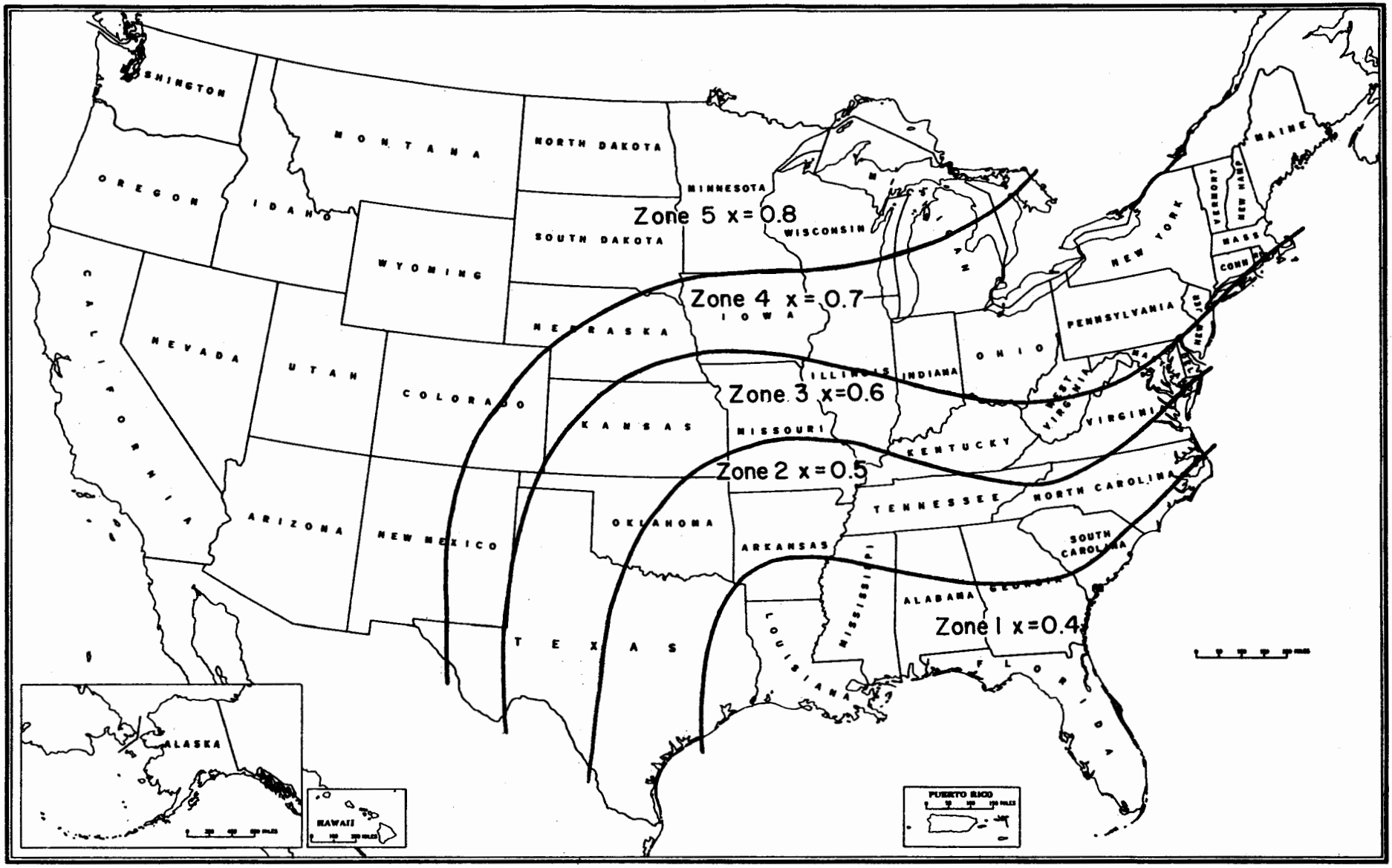


Figure 4.5

Values of x in equation V.1=xs+y

3. DESIGNING THE TERRACE SYSTEM (CONT'D)

Using Universal Soil Loss Equation (cont'd)

"P" factor for various land slopes

Percent Slope	Lister Planting	Surface Planting
1.1 - 2.0	.45	.60
2.1 - 7.0	.38	.50
7.1 - 12.0	.45	.60
12.1 - 18.0	.60	.80
18.1 - 24.0	.68	.90

To show how the Universal Soil Loss Equation may be used to determine terrace spacing, use the following sample problem and solution:

Problem: Determine terrace spacing for a 7% slope on a Marshall Silt Loam Soil located in the northeast corner of Kansas. Two possibilities of cropping systems are being considered:
(1) 5-year rotation of corn, oats, wheat with sweet clover, sweet clover.
(2) 4-year rotation of corn, oats, wheat with sweet clover, sweet clover.

Solution: (1) 2-year lister planting, 3 years surface planting - P = .45
(2) 1-year lister planting, 3 years surface planting - P = .47

"E" for Marshall Silt Loam = 5.0
"K" for Marshall Silt Loam = .32
"R" for northeast Kansas = 190
"C" for rotation (1) = .24
"C" for rotation (2) = .16

(1) Then SL = 5 * .32 x 190 x .24 x .45 (first rotation)
(2) And SL = 5 * .32 x 190 x .16 x .47 (second rotation)
(1) Then SL = .76
(2) SL = 1.09
*(1) L for 7% slope when SL = .76 is 90 feet (approximately)
*(2) L for 7% slope when SL = 1.09 is 175 feet (approximately)

*Formula to calculate "Lp" when SL has been determined:

$$SL = \frac{\sqrt{Lp}}{100}\left(0.76 + 0.53S_i + 0.076S_i^2\right) \text{ or}$$

$$Lp = \left[\frac{100SL}{0.76 + 0.53S_i + 0.076S_i^2}\right]^2$$

Where "S_i" is land slope in percent.
Lp is horizontal terrace spacing in feet.

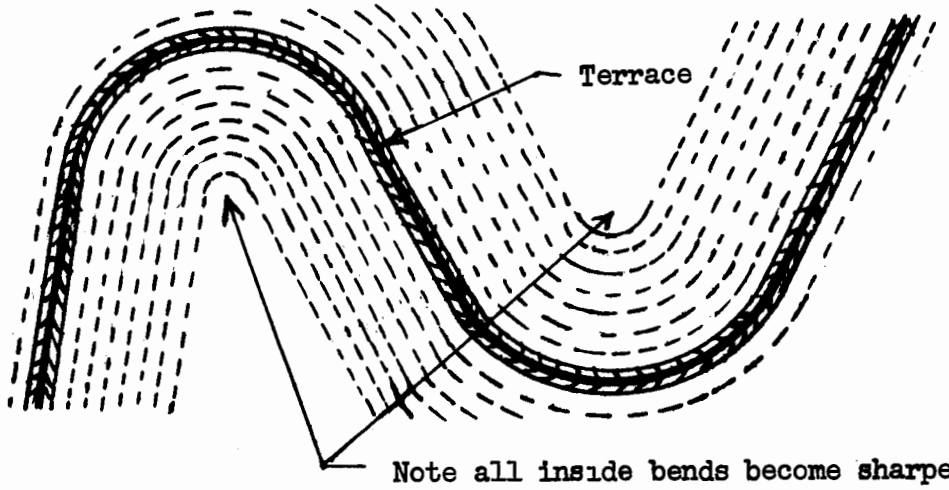
4. LAYOUT OF TERRACE SYSTEM

General

The layout of terrace systems in many cases has consisted of merely determining the spacing from a formula, selecting an allowable grade, and then mechanically staking the terrace line. The importance that terraces play in both erosion control and moisture conservation justifies far more attention to the layout than this mere mechanical operation. When terraces are constructed, it is expected that they will be a permanent part of the farm for the next 20 to 30 years and that with the help of other conservation practices soil losses will be held to a minimum.

In the layout of terraces there are five things which should receive careful attention to assure that the system will be as practical to farm as the physical conditions of the field will permit. These are (1) sharp bends in the terrace lines, (2) approaching obstacles at acute angles, (3) unnecessary point rows, (4) crossing narrow ridges with terraces, and (5) adequacy of outlets.

(1) Sharp bends are difficult to make with modern farm equipment. They are especially troublesome wherever farm equipment must turn inside the bend because they become sharper as farming operations proceed away from the terrace line.



AVOIDING SHARP BENDS
Figure 4.6

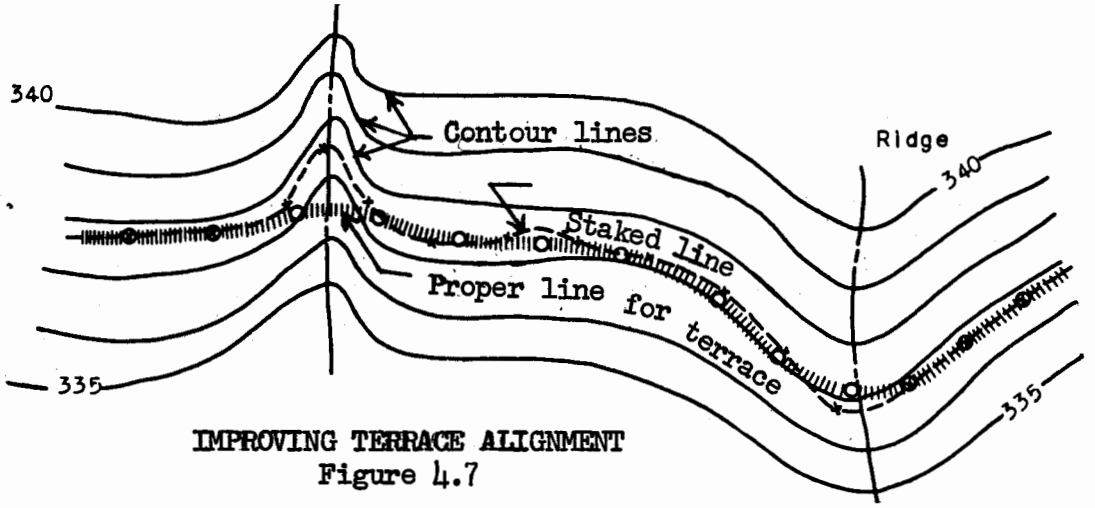
4. LAYOUT OF TERRACE SYSTEM (CONT'D)

General (cont'd)

(2) Approaching obstacles at an acute angle make farming operations very difficult as this results in sharp corners where it is virtually impossible to turn farm equipment. Terrace lines approaching narrow drains tend to turn up rather abruptly. If these drains are used as waterways, the terrace ends can be lowered sufficiently to provide good terrace drainage and also to eliminate the sharp angles. Farming operations or soil blowing frequently have caused field boundaries to be higher than the adjacent field. In such cases the terrace lines would turn rather abruptly down the boundary line. To prevent this, the terraces can be blocked if an adequate outlet is provided at the other end. If terraces must spill at this end, the high area along the boundary can be left as a road and the terraces ended before reaching the high area and a waterway provided between the terrace and the farm road.

(3) Unnecessary point rows are one of the main reasons that farmers retire terraced fields from cultivation.

If terraces are to be maintained and serve their intended purpose for several years, they must fit into an economical farming operation. To best do this, it is imperative that as many point rows be eliminated as is practical. Terrace layout, therefore, becomes an engineering planning and design procedure rather than a mechanical line running process.



IMPROVING TERRACE ALIGNMENT
Figure 4.7

A great deal can be done with both level and graded terraces to make them more nearly parallel. Point rows can be eliminated in level terrace systems by making line adjustments with cuts and fills along the terrace lines. Level terrace systems where groups of terraces can be made parallel are limited to uniform fairly flat slopes, but many point rows can be eliminated in nearly any system. Point rows can be eliminated in gradient terrace systems by both changes in grade and by cuts and fills along the terrace lines.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

General (cont'd)

(4) When terrace lines cross narrow ridges, they generally require sharp bends. If adequate outlets are provided in the natural drains, the terraces can end on each side of the ridge. When this is done, the ridges provide excellent field roads and help to keep the farm waterways from being used as farm roads.

(5) A common practice is to provide terrace outlets at the field boundaries and to cross the natural drains with the terrace ridges. Field boundaries generally have steeper slopes, poorer soils, and shapes less suited for waterway use than do the natural watercourses. It is normally best to use the same locations for waterways that nature has provided to dispose of excess water. An adequate number of outlets should be provided. The greater the number of outlets that are provided, the more can be done to make the terrace system more farmable.

The Key Terrace

As a general rule, the upper terrace is staked first and each succeeding terrace staked in turn. An exception to this rule may be made if it is desired to have a definite location for some particular terrace in the system. This terrace would then be located first and a sufficient number of terraces staked between it and the drainage divide to insure that the maximum vertical interval for any one terrace would not be exceeded.

The location and construction of the top terrace is very important. If the top terrace fails, it often causes the failure of the lower terraces.

Some general rules for location of the top terrace are:

If the top of the hill comes to a point, the interval may be increased to one and one-half times the regular terrace interval.

On sharp sloping ridges, the interval may be increased to one and one-fourth times the regular terrace interval.

On long ridges where the terrace approximately parallels the ridge, the regular interval should be used.

The watershed area above the top terrace should not exceed the area obtained by multiplying the terrace length by the normal terrace spacing for the slope and soil above the top terrace.

Staking the Graded Terrace Outlet

A method of staking a terrace outlet is shown in Figure 4.1. A drop of 1.1 feet is given the last 100 feet. Of this amount, 0.4 feet is the

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

Staking the Graded Terrace Outlet (cont'd)

continuation of the 0.4% slope, 0.5 feet is allowed for the depth of channel excavation, and 0.2 feet is given to clear trash and silt. If a drop of 0.5 feet is not allowed for the depth of channel excavation, the grade of the channel will rise in the last one hundred feet and the cross section of the channel at Station 13+00 will be restricted. The need for a drop of 0.2 feet to clear trash depends upon local conditions.

Since the longitudinal section of the channel excavation feathers out as the channel grade meets the grade of the outlet, there will not be enough dirt available from the channel excavation to build the terrace ridge. Earth to make the fill can be had by deepening the channel with the expectation that the pit will silt up in time or the fill can be made by borrowing material elsewhere. The photograph in Figure 4.1 gives another illustration of the principles involved in staking the outlet of a terrace.

Determining the Vertical Interval

On fairly uniform slopes the average slope of the area can be used in computing the vertical interval for the terraces. If the slopes vary considerably, the weighted average of all the slopes that a terrace is to cross should be used in computing the vertical terrace interval for each terrace. On some fields it may be advisable to reduce or increase the indicated interval for certain terraces in the system in order to place them advantageously. It may also be necessary to make adjustments between terrace intervals for graded terraces in order to get proper alignment at the outlet. Very frequently special consideration must be given to factors other than vertical interval alone in determining the location of the top terrace of a system due to the peculiar shape and direction of slope of the top portion of the area to be terraced. There may be an abrupt change in slope on some part of a field. It may be necessary to place the terrace either just above or just below the slope. This becomes a key terrace and others are placed in proper relation to it.

For graded terraces, it is usually found most convenient to start staking at the outlet end particularly if there are terraces discharging into both sides of the outlet so that proper alignment is attained. Stakes should be set at 50-foot intervals except on curves and through draws where a 25-foot spacing should be used. Where topography is uniform, 100-foot and 50-foot spacing, respectively, may be satisfactory.

It is not always possible to secure the most satisfactory terrace layout in the first attempt. After a few lines have been staked, topographical features will sometimes be encountered that will favor changes in terrace lines. If such changes are extensive, it is usually best to pull up all stakes and start over again.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

Determining the Vertical Interval (cont'd)

After the terrace lines have been staked, some realignment is necessary on each proposed terrace in order to eliminate undesirable sharp curves, to obtain greater ease of construction, and to secure a finished terrace that will offer a minimum of inconvenience in later tillage operations. The general procedure is illustrated in Figure 4.7. The movement of terrace lines up and down slopes will, of necessity, be restricted by the drainage and construction features encountered. Usually the straightening should be limited in upward movement so that not more than a 6-inch additional cut will be necessary in the terrace channel and the number of cuts of this depth should be kept to a minimum. The straightening of terraces through depressions should not be such as will introduce excessive ridge heights and objectionable pond areas.

Relation of the Staked Line to the Completed Terrace

Graded Terrace. The channel is constructed on the stake line to make the constructed channel grade the same as the designed grade. Additional depth of channel cuts is made to compensate for any uphill adjustment of the stake line of ridges. Additional height of ridge fill is made across gullies, narrow depressions, or lows resulting from any downhill adjustment of the stake line.

Level Terrace. The ridge is built on the surveyed stake line to make the constructed ridge a level impounding levee. Fills are made in low spots to make the settled ridge top level.

Adjustments to Improve Terrace Alignment

Figure 4.8 shows a topographic map with contours taken in the field at 5-foot vertical intervals and interpolated at 1-foot intervals on the map. The 1-foot contours are shown in dotted lines. The lines with arrows show scaled slopes.

A system of terraces has been plotted on this map beginning with the top terrace and proceeding down the slope.

The stippling shows the areas of variable width between the terraces. These irregular areas cause point rows which increase the number of turns required in cultivation and add to the cost of farming. If, by care in planning, point rows can be eliminated or reduced, the cost of cultivation can be reduced.

It is desirable sometimes to use greater refinement in the design of terrace systems to eliminate point rows or otherwise improve the system than can readily be obtained by field observation. For this purpose, topographic maps are particularly useful.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

Paralleling Terraces

In laying out terraces, it is frequently possible to make a pair of terraces parallel throughout or in part and thus reduce the number of point rows in a field.

In view of the time and effort saved for the farmer over a period of years if a set of point rows is eliminated, the technician is justified in spending several hours, if necessary, to accomplish this.

If several of the natural drains are used as waterways the paralleling of terraces is more readily accomplished.

The maximum spacing of parallel terraces should be in accordance with the spacing criteria for standard terraces. The use of parallel terraces eliminates to a great extent the objection to narrow spacing as turning within the field is eliminated. Spacing used should be within the above maximum but should be adjusted to fit complete trips of least flexible farm equipment that will be used.

The amount that terrace lines can be moved for terrace alignment is dependent on the maximum allowable grade and on the permissible cut to be made. For level terraces, the maximum permissible cut would govern.

Two systems for the layout of parallel terrace systems are recommended. Which one is used is dependent on the uniformity of the slopes to be terraced.

System 1 - Uniform Slopes. Beginning at the highest part of the field, the slope should be measured to approximately the center of the field in sufficient detail to determine the number of and general location of terraces.

Then the key terrace should be staked to grade. This key terrace will usually be located about midway down the slope. Sharp bends and minor irregularities should be corrected on this terrace line and the line marked out by use of farm tractor or other positive means of line marking. Using a small rope or similar measuring device, stake two terrace lines parallel to this terrace on the selected vertical interval and horizontal spacing, one on each side of the key terrace. One man will walk along the key terrace and make sure the rope is perpendicular to the line as the second man marks the adjoining parallel lines. The final location of the line is best made by use of the farm equipment with a spacing marker to assure that spacing is kept uniform on curves. The final line is then checked to determine if it meets layout requirements.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

System 1 - Uniform Slopes (cont'd)

Additional parallel terrace lines are run in the same manner until the allowable grade plus maximum determined cut is exceeded. When this is the case, another series of terraces are laid out in the same manner. To determine when a new series of terraces must be started, rod readings or elevations should be taken on the staked lines. These readings are plotted on profile paper and lines drawn that will balance cut and fill. These lines must be within the allowable grade.

System 2 - Irregular Slopes. For irregular slopes, the entire set of terraces is staked out as for conventional terraces. Key terraces are then selected that best fit in with terraces on both sides. Short sharp bends and minor irregularities are then corrected on the key terraces, a number of measurements made between the key terrace and adjoining terrace to determine the average horizontal spacing that will fit the farm equipment to be used, and the adjoining terraces made parallel to the key terrace in the same manner as in System 1. In some cases only sections of the terraces can be paralleled but even partial paralleling can result in considerable reduction of the number of point rows.

An alternate system that makes use of a grid survey is an excellent method of laying out terraces. A grid map on 100-foot centers is made of the field to be terraced. Terraces can then be planned on the grid map and transferred directly to the field by measuring the lines in from the grid points. This method may require somewhat more time than the others but generally results in a better terrace layout as location of key terraces is easier to determine and allowable alteration of terrace lines can readily be made.

If paralleling is accomplished to the point that cut and fill terraces are to be made, it will be necessary to obtain elevation readings at each stake line on the parallel lines. For uniformity of construction, the stake line is usually at the intersection of the terrace ridge front slope and the terrace channel.

If paralleled terraces are to be constructed with motor grader, bulldozer or similar equipment, the ground along the terrace line will need to be brought to the elevation of the grade line. If the terraces are to be constructed with carry-all type equipment, then the terrace channel and ridge will be shaped as excavation and fill are made. This will eliminate the need of moving the ridge portion of the terrace where this portion is above the average ground line but not above the top of the terrace ridge.

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

System 2 - Irregular Slopes (cont'd)

Figure 4.9 shows a revised layout of the terrace system shown in Figure 4.8. In the revision, terraces have been made to lie more nearly parallel to each other and thus reduce the number and size of irregular areas. An inspection of the two layouts will show the amount of this reduction. To accomplish this result, the positions of the terraces have been altered by changing the location of summits which in turn have changed the total fall of the terraces. Grades have been steepened at the upper ends of terraces (summits) where the volume of water carried by the terrace is small. Thus, it has been possible to make terraces 1, 2, and 3 parallel to each other and eliminate irregular areas between them. In laying the lines in the field, terrace 2 would be staked according to grade elevations shown and terraces 1 and 3 would be placed by measuring uniform distances from terrace 2. Grade elevations would be checked for terraces 1 and 3 to insure an acceptable grade line. Terraces 3 and 4 have been made partially parallel to each other by varying the grades on terrace 4. Part of terrace 4 has a variable grade as shown and part of it has a uniform grade of 0.5 feet per 100 feet. In this way, the size of the irregular area between these two terraces has been reduced.

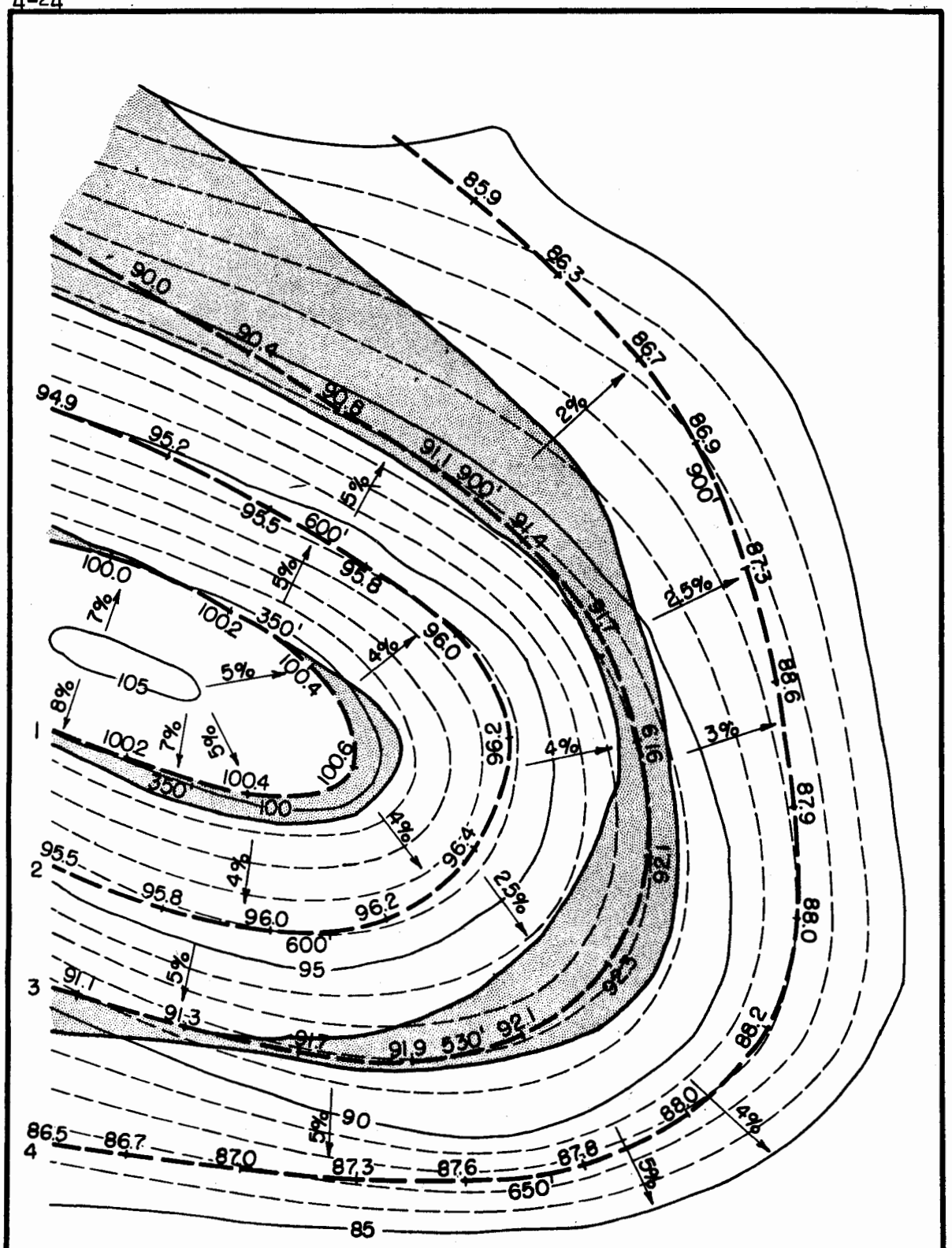
It will be seen that terrace layout 2 can be farmed more easily than terrace layout 1.

In areas where soils are permeable and slopes are uniform, considerable paralleling of terraces has been done to advantage.

In areas where soils are impervious and slopes are irregular, it is difficult to parallel terraces without causing objectionable ponding.

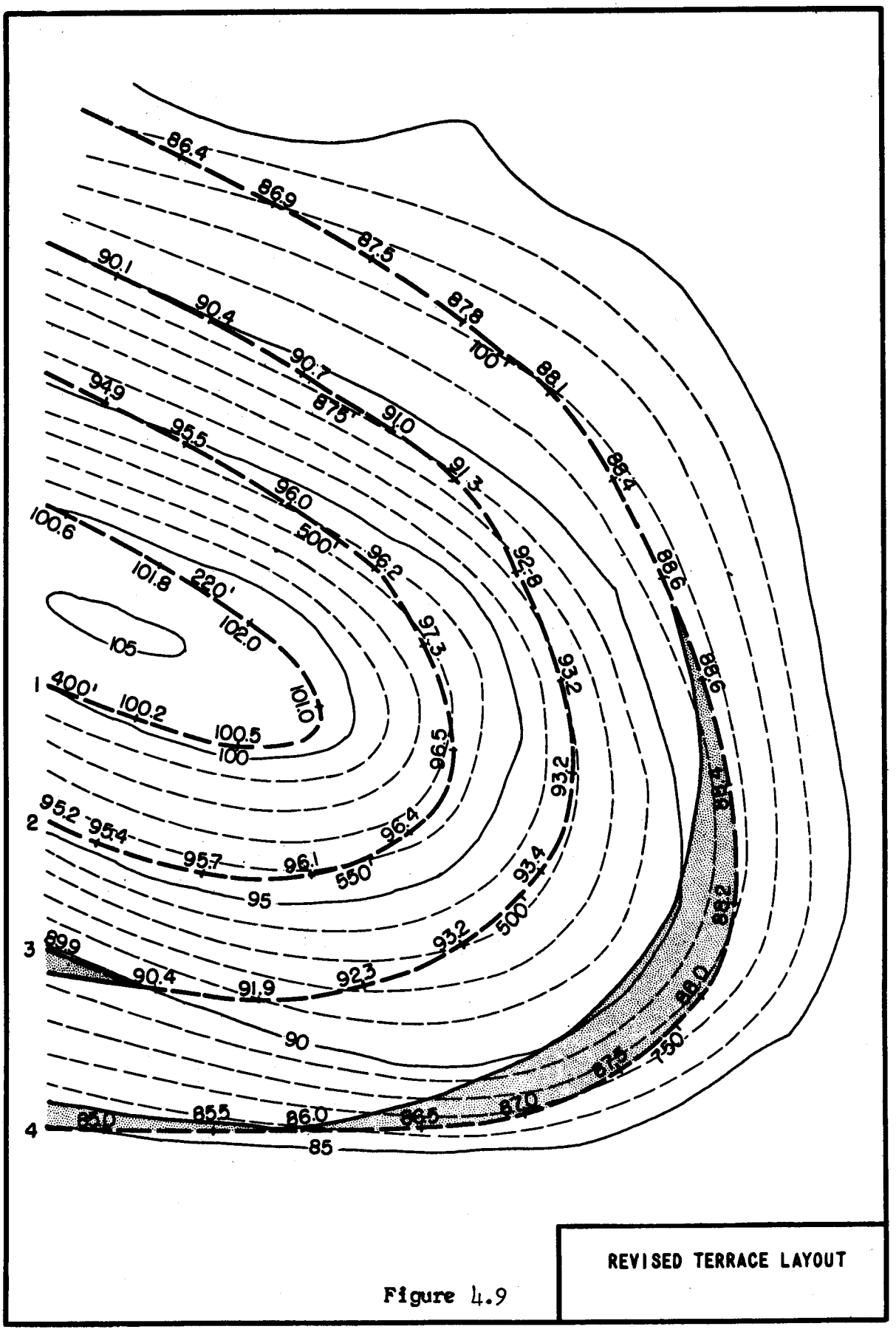
In attempts to make lands between terraces uniform in width, care should be used to avoid excessive cuts and fills. While soil types will influence the limits, in general, cuts should not exceed one-half foot below the usual terrace channel and fills should not exceed moderate heights.

Also, terrace grades should be sufficient to provide proper drainage, but they should not be so steep as to cause erosion in the terrace channels and the washing out of crops.



TERRACE LAYOUT

Figure 4.8



REVISED TERRACE LAYOUT

Figure 4.9

4. LAYOUT OF TERRACE SYSTEM (CONT'D)

System 2 - Irregular Slopes (cont'd)

On large fields it is seldom possible to parallel the terraces over an entire field. More often it is possible to parallel groups of terraces or portions of groups where slopes are regular.

Staking Cuts or Fills Where Alignment is Improved

If the terrace as finally laid out varies from the planned grade line by more than approximately 0.2 foot, it will be necessary to set cut and fill stakes to guide the equipment operator in installing the structure. If the variation is only for short segments through narrow ridges or across narrow drains, cuts and fills can readily be determined from the original line survey.

When the terrace line varies from the planned grade line for an appreciable portion of the total length, it is generally advisable to profile the entire line and then determine the extent of cuts and fills necessary.

Where the construction line is within the approximate 0.2 of the surveyed line, the equipment operator can normally construct the terrace without additional cut or fill stakes.

The technician planning or laying out the terrace system should keep in mind that every point row that can be eliminated will result in a saving in farming cost for a number of years. Even though only segments of terraces can be paralleled, this is much preferred over no paralleling at all.

PATTERN OF LAND USE AND EXPECTED SOIL LOSS PER ACRE FOR SPECIFIED ROTATIONS AND PRACTICES ON MARSHALL SILT LOAM SOILS WHERE THE DOMINANT SLOPES ARE ABOUT NINE PERCENT.

Rotation*	Percent of land in		Corn percent	No Mechanical Practices tons	Contouring but no terraces tons	Contouring and Terraces tons
	Meadow percent	Small Grain percent				
CCOM	25	25	50	39.2	19.6	2.0
COM	33	33	33	28.0	14.0	1.4
CCOMM	40	20	40	25.2	12.6	1.3
COMM	50	25	25	16.8	8.4	0.8

* C = Corn
  O = Oats
  M = Meadow

Iowa Farm Science, Iowa State College, Vol. 4, No. 5, November 1949

Figure 4.10

5. CONSTRUCTION OF TERRACES

Preparation of the Field

All dead furrows or ditches to be crossed should be filled in before the construction begins to prevent seepage through terrace ridge and to facilitate construction.

All old fence rows should be leveled off.

Surplus vegetation should be removed.

Heavy sod should be thoroughly disked.

Methods of Terrace Construction

Building Terraces with a Motor Grader. The Patrol grader is an excellent tool for building terraces. Since the blade is reversible, dirt can be moved either to the right or left which permits the moving of earth from the upper or lower side of the terrace at will. The size of the cut taken by the blade depends upon the size of the equipment and the toughness of the soil. The load is adjusted by raising or lowering the heel of the blade to keep the machine from skidding. The angle of the blade should be such as to roll the dirt and not just slide it ahead.

Figures 4.11 and 4.12 show the positions of grader blade cuts and sequences of operations for terraces built with earth taken from the upper or both sides of a terrace. The number of rounds indicated are not necessarily the number of rounds required to construct a terrace to the desired specifications. The upper photograph in Figure 4.13 shows a motor grader cutting the back slope of a terrace.

Building Terraces with a Moldboard Plow. The plow should be in good mechanical condition. Plow shares should be sharp. Power should be sufficient to maintain a fast speed so that the dirt can be thrown from the moldboard.

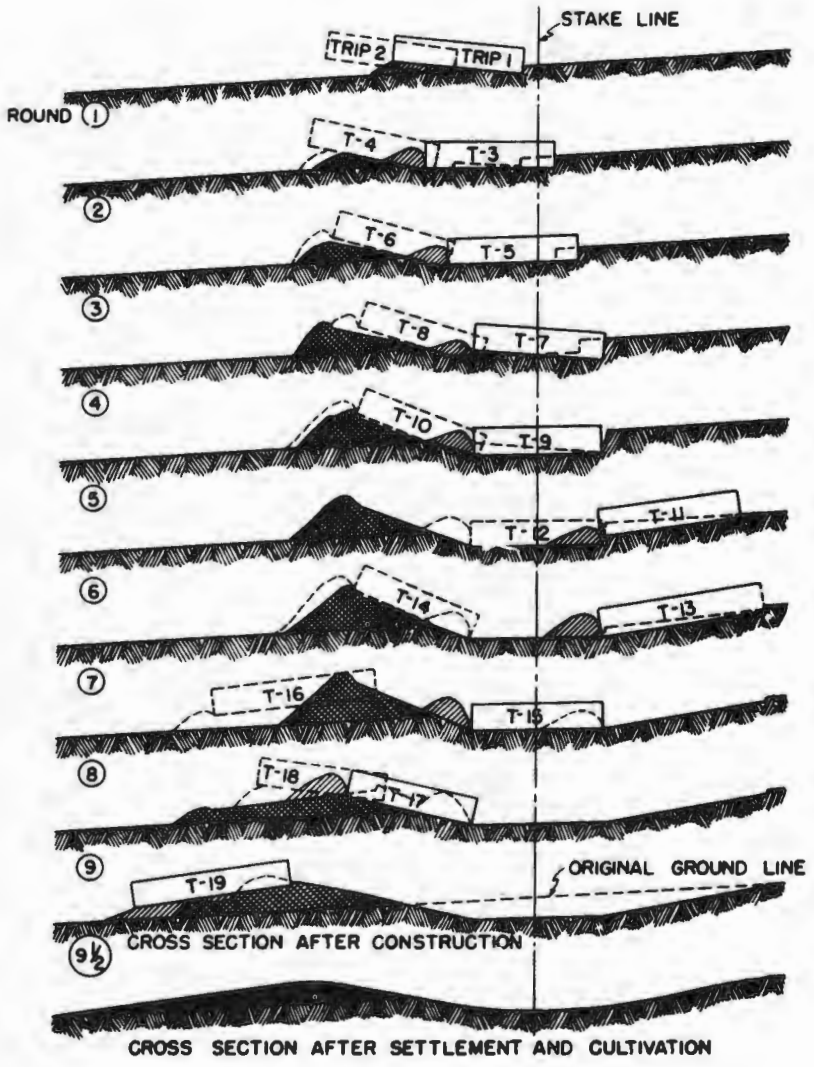
Trash should be cleared from the area to be plowed if it is heavy enough to interfere with the plowing.

The lower photograph in Figure 4.13 shows terrace construction with a moldboard plow.

When soil is in good condition for plowing it is in good condition for terracing with a plow.

Figure 4.14 shows the position of plow furrows and the sequence of operations in the building of a terrace with a two-bottom moldboard plow. Rounds are numbered to show sequence in plowing for this particular method and do not indicate number required to complete a terrace to specifications. Usually about 40 rounds are required to construct a good terrace.

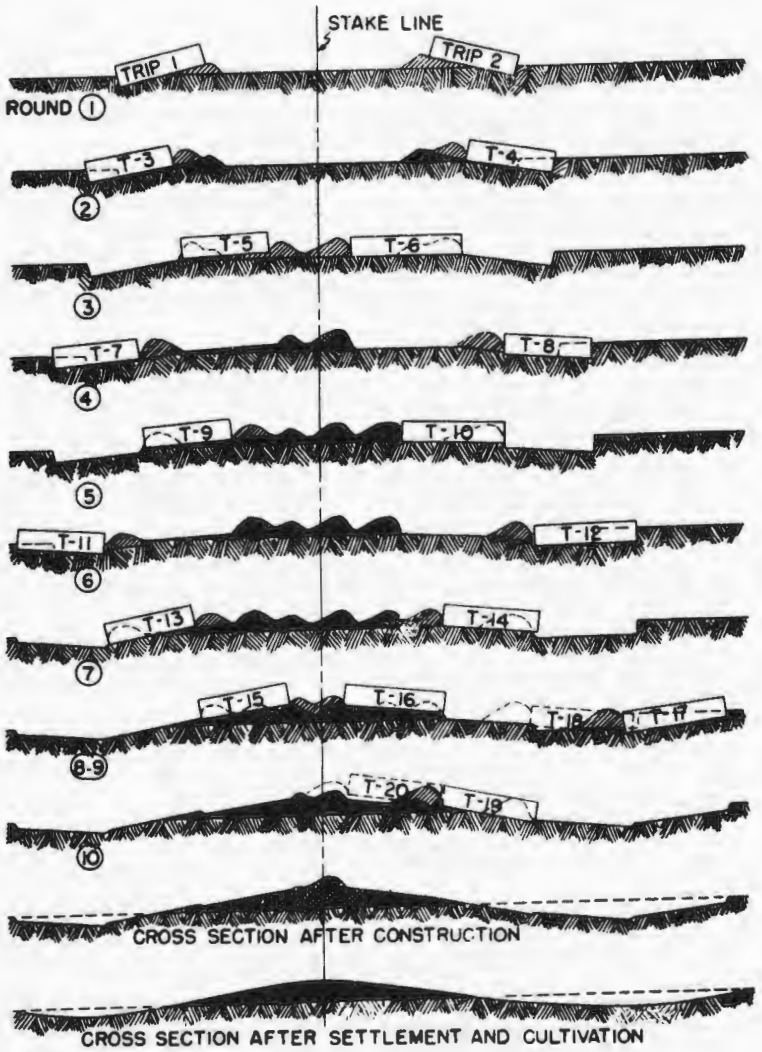
Before plowing is started a second line of stakes should be set 8 to



Progressive steps of one common method of constructing a terrace from one side with a 10-foot blade grader or terracer. The terrace is constructed from the upper side only. The trip and round numbers are primarily intended to show the sequence of the operations. Different conditions will require more or less rounds than those shown.

Figure 4.11

TERRACE CONSTRUCTION by Patrol Grader



Progressive steps in constructing a terrace from both sides with a 10-foot blade grader or terracer. The terrace is constructed from both sides. With inexperienced operators and on certain soil types it may be desirable to secure the necessary center height in the first few rounds.

Figure 4.12

TERRACE CONSTRUCTION by Patrol Grader

TERRACE CONSTRUCTION WITH PATROL GRADER

TERRACE CONSTRUCTION WITH A MOLDBOARD PLOW

Figure 4.13

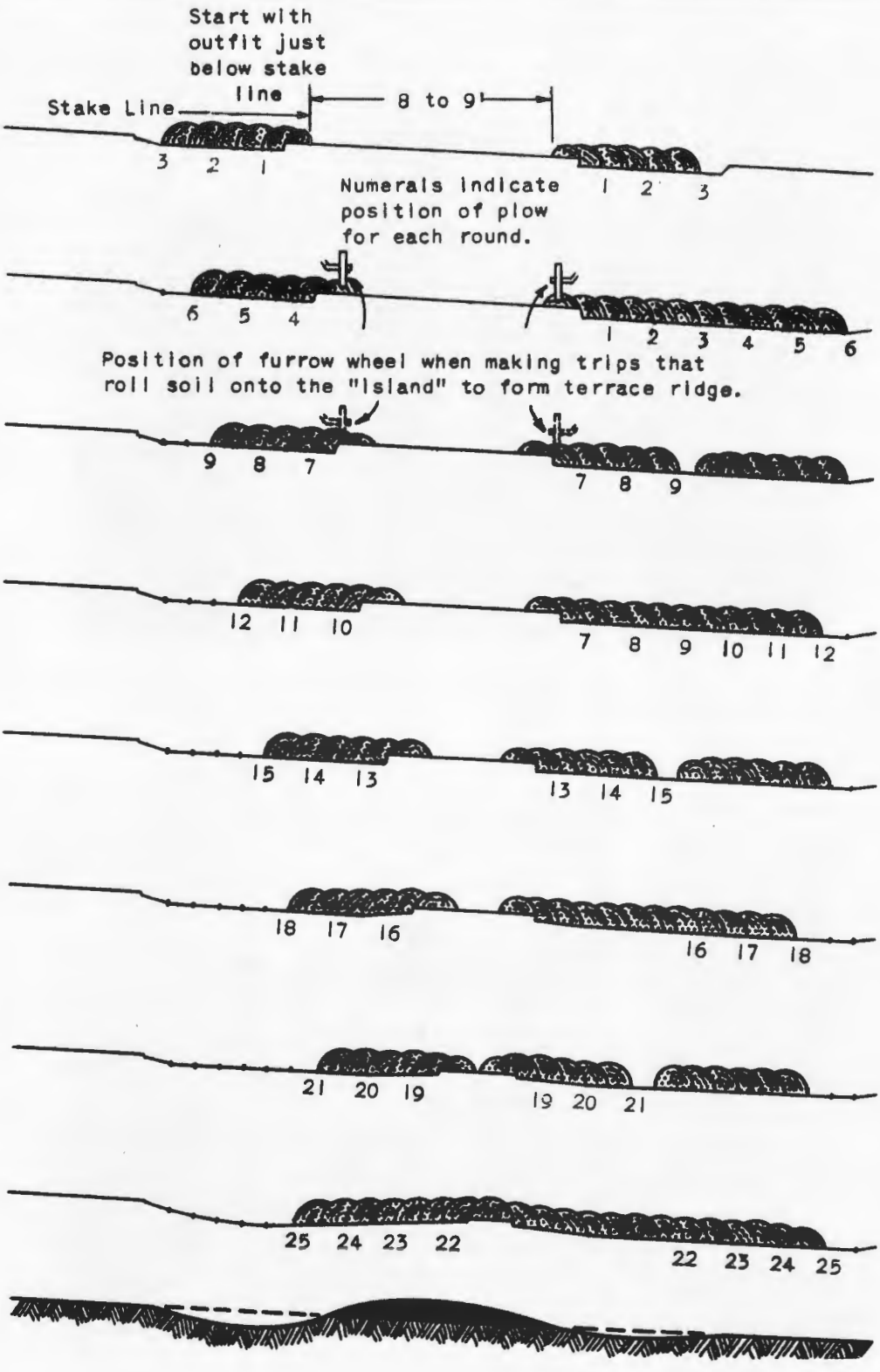

Start with outfit just below stake line
Stake Line
8 to 9
3 2 1
1 2 3
Numerals indicate position of plow for each round.
6 5 4
1 2 3 4 5 6
Position of furrow wheel when making trips that roll soil onto the "island" to form terrace ridge.
9 8 7
7 8 9
12 11 10
7 8 9 10 11 12
15 14 13
13 14 15
18 17 16
16 17 18
21 20 19
19 20 21
25 24 23 22
22 23 24 25

Figure 4.14

TERRACE BUILDING WITH 2-BOTTOM TRACTOR MOLDBOARD PLOW

5. CONSTRUCTION OF TERRACES (CONT'D)

Building Terraces with a Moldboard Plow (cont'd)

9 feet below the original line of terrace stakes. In order that the tractor driver may follow staked lines closely and plow strips of uniform width, all stakes should be 50 feet apart on gentle curves and 25 feet apart on sharp ones. The strip between the lines of stakes is known as the "island". Dirt is plowed over dirt to form a ridge on this island which is the "secret" of successful terrace building with a moldboard plow.

For graded terraces locate the island below the stake line. For level terraces center the island on the stake line. The island width is an important factor related to the size of terrace to be built.

The plowing for the first set of three rounds should be about four inches deep. Subsequently, as dirt is plowed over dirt on succeeding sets of rounds, the depth of the plowing should be increased an inch for each set so that the plows will cut a little solid earth.

As earth is moved toward the center of the island on each subsequent set of rounds, the plow should be set over one plow width (14 inches) and under the loose dirt of the previous plowing. If it is set over more than a plow width the center will be reached more quickly but less earth will be moved into the terrace ridge.

On the steeper slopes it is desirable to lessen the steepness of the back slope by making more cuts on the upper side of the terrace than on the lower. Then the plowing can be extended out into the field on the return trip on the lower side or the return trip can be used to pack the loose dirt on the upper side.

Usually it is necessary to use a scraper or a bulldozer to make fills in a plow-built terrace.

Variations can be made in the procedure just described to meet the needs of particular situations and also the desires of the builders. The proportion of earth taken from the upper or lower side can be varied by varying the number of trips on either side.

A 3-bottom plow can be used rather than a 2-bottom, if desired.

Building Terraces with a Disc Tiller. Terraces can be built by using a disc tiller with 24-inch or greater diameter discs. Smaller discs are not recommended.

A 4-foot disc tiller with 5 discs drawn by a 20 H.P. tractor on rubber provides a good construction unit. Enough power and speed is provided by the tractor to throw the dirt rather than just turn it over.

When soil conditions are favorable for plowing, they are favorable for terrace construction.

5. CONSTRUCTION OF TERRACES (CONT'D)

Building Terraces with a Disc Tiller (cont'd)

Figure 4.15 shows the steps in an actual construction of a terrace with a disc tiller by what is known as the "step in" method. Since there is nothing to be gained by disturbing soil which will be under the final terrace ridge, first cuts are made at the distances shown from the staked center line of the ridge. Loosened dirt is then moved into the ridge. Subsequently other cuts are made at greater distances from the center line and the loosened earth is moved into the ridge until the desired terrace cross section is obtained. There is no exact position or sequence of cuts to fit all conditions. But the amount of dirt loosened and moved to the center should be what the unit can handle effectively. The loosened ridge of earth should not be so great that the tractor and tiller will flounder around in it and lose effective effort.

If a larger proportion of earth is to be taken from the upper than the lower side, subsequent rounds on the lower side may extend out into a plowing operation.

The number of rounds required to build a terrace depends upon the size of the terrace desired, the size of the equipment and the effectiveness of its performance. It also depends upon the width of the plow, the speed of the tractor, and the soil.

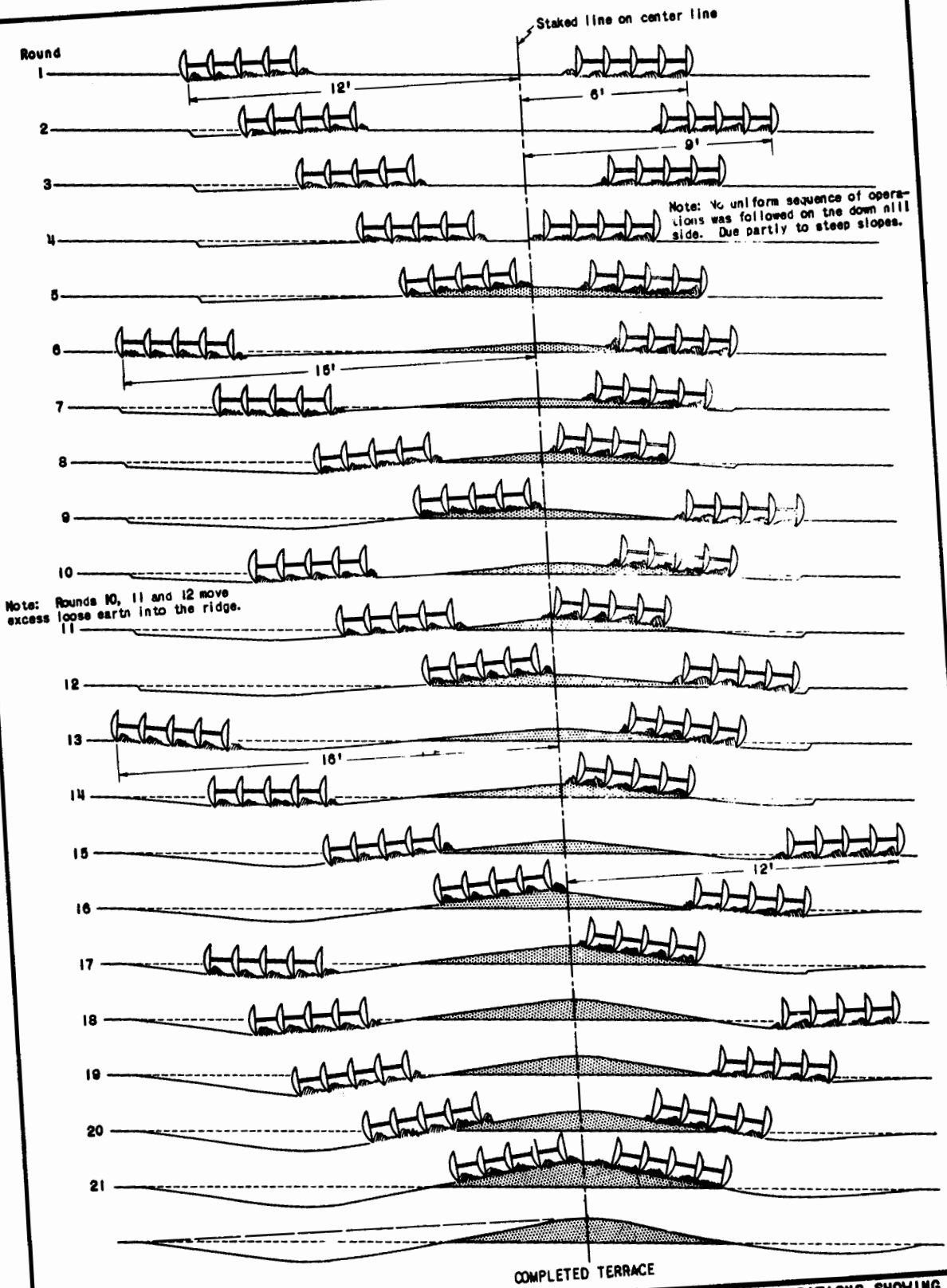


Figure 4.15 DIAGRAM OF OPERATIONS SHOWING CONSTRUCTION OF A TERRACE WITH A 4 FT. DISC TILLER. SLOPES 8 TO 12%

5. CONSTRUCTION OF TERRACES (CONT'D)

Constructing Terraces with an Elevator Terracer

Terraces can be constructed by an elevator type terracer pulled by a farm tractor. Mounted elevator equipment on farm tractors or motor graders is also very efficient in building the body of the terrace. This type of equipment usually moves earth 10 to 14 feet and permits building the terrace ridge on a solid "island" of earth.

Since an elevator terracer throws earth in one direction only, the terrace ridge is built from both sides. This procedure limits use of the equipment to slopes on which terraces can be built from both sides unless the machinery is "deadheaded" and extra trips made on the uphill side of the terrace ridge. It is difficult to build a terrace from the downhill side on slopes in excess of 5%.

The sketch below shows the various cuts made by the elevator and relative positions of the earth deposited on the "island".

TERRACE CONSTRUCTION BY ELEVATOR GRADER OR TERRACER

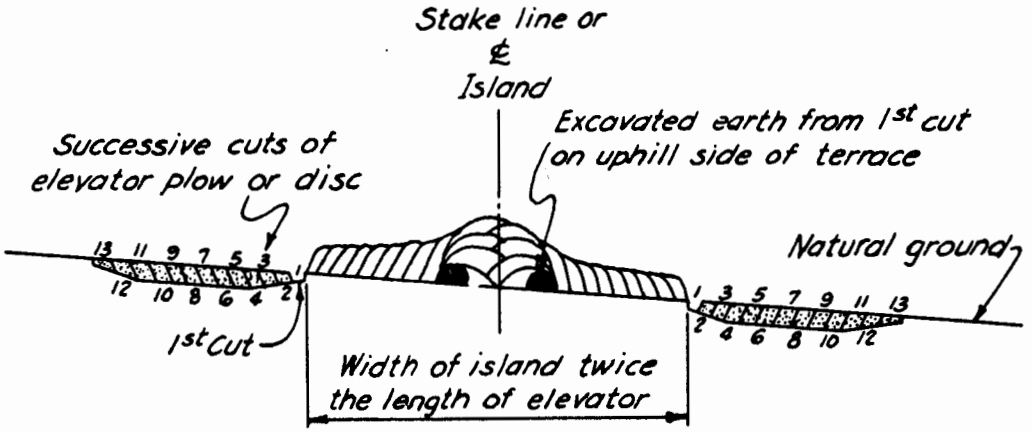

Stake line or
℄
Island
Excavated earth from 1st cut
on uphill side of terrace
Successive cuts of
elevator plow or disc
Natural ground
13 11 9 7 5 3 1
12 10 8 6 4 2
1 3 5 7 9 11 13
2 4 6 8 10 12
1st cut
Width of island twice
the length of elevator

Figure 4.16

Start construction with an "island" twice as wide as the length of the elevator and with the stake line in the center. The earth will be carried farther than the elevator length and will overthrow the center of the island for the earliest rounds. This gives the necessary height to the ridge in the first few rounds.

5. CONSTRUCTION OF TERRACES (CONT'D)

Figure 4.17

Light cuts should be made in the first few rounds so that the excavated areas are properly shaped and for successful operation of the elevator belt and rollers. Full cuts are made after the first few rounds. The outside edges of the excavated areas can also be shaped to meet the natural ground by reducing the depth of cut as the machine moves outward from the terrace ridge.

Fourteen to twenty rounds are usually necessary to construct a suitable terrace, depending on the size and the degree to which the elevator is used to provide for a smooth, uniform cross-section. The width of cut taken by the machine will also vary the number of rounds necessary to construct the ridge. Small elevators that are tractor mounted do not throw the earth as far and more rounds are needed for this type of equipment.

Figure 4.18

5. CONSTRUCTION OF TERRACES (CONT'D)

Bulldozer. The bulldozer is an efficient terracing machine under any condition. It can be used on very rough, stony, and eroded soils. The ditches can be filled as part of the terrace construction operation. The bulldozer will operate under conditions in which other types of equipment cannot efficiently function, such as in extremely dried-out soils. Two methods have been used as shown in Figure 4.19.

The roughing-in is accomplished by making three "cuts" and "bucks". After the roughing-in is completed, two rounds or more are made lengthwise to shape the slopes and sometimes one in the channel is necessary to give the terrace its final shape and cross section.

Checking the Finished Terrace

After a terrace has been built, it should be checked for correct grade, height and sufficient cross section. High spots in the channel which will prevent flow in drainage terraces should be lowered to grade. Low places in the terrace ridge should be raised so that breaks will not occur at these points. The upper end of drainage terraces should be raised to a steeper grade or blocked so that water does not flow out. The outlet end of drainage terraces should provide for free flow into the outlet. The ends of level terraces should be checked to see that they provide the closure specified.

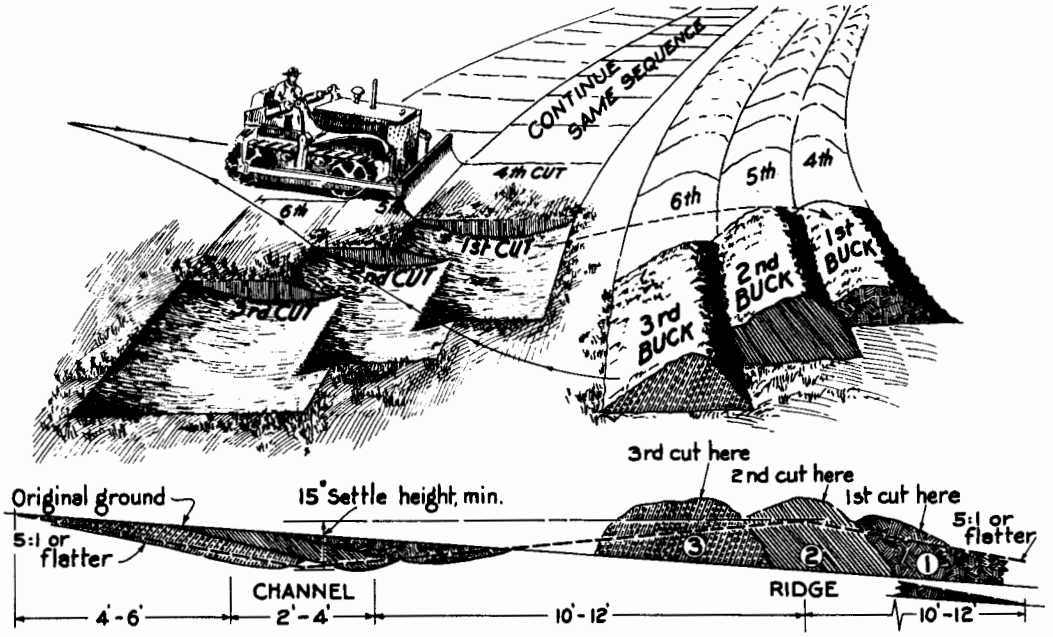
The high and low points should be marked so that the necessary corrections can be made. Prevent ponding in graded terraces over 0.1 foot deep. This is always a hindrance to operation of farm equipment and it causes crop loss.

When checking level terrace the ridge height should be checked carefully for low spots and the ridges strengthened at gullies and ravines.

6. TERRACE MAINTENANCE

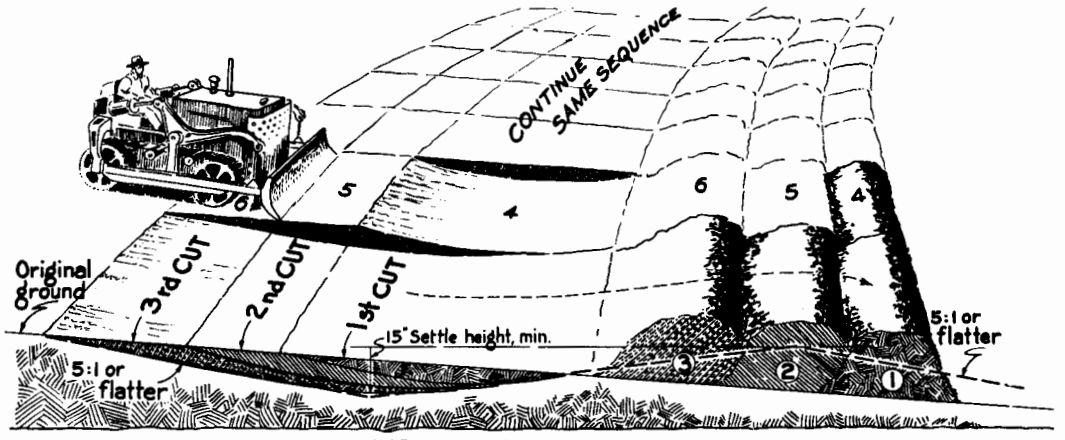
Control of Inter-Terrace Erosion

Terraces are designed and constructed with sufficient capacity to adequately handle the runoff that could normally be expected from the area above them. Any factor tending to decrease this capacity will automatically lower their efficiency and increase the possibility of serious breaks during heavy rains. The two things that contribute to this decrease in capacity are silt accumulation in the channel from the cultivated area above, and the working down of the ridge by normal cultivation practices. While these two contributing factors can be reduced to a minimum by proper rotation and tillage practices between the terraces and by proper care in farming on the ridges, they cannot be eliminated completely and unless compensated for by maintenance practices, will gradually lead to complete deterioration of the terraces.



Cross Section of Terrace

STAGGERED CUT METHOD



STRAIGHT CUT METHOD

A METHOD FOR TERRACE CONSTRUCTION WITH BULLDOZER

Figure 4.19

6. TERRACE MAINTENANCE (CONT'D)

Repair of Fills in Terrace Ridge

For the first season or two after construction, the farmer should be encouraged to be on the lookout after rains for low places in the ridges and should make additional fills when these occur. Although terraces are checked during construction, a ridge may settle more in one place than in another, leaving a low spot that will reduce the effective height of the entire terrace. Occasionally a high spot in the channel will also be noticed, and whenever such is found, it should be cut out.

Repairs in fills should be higher and broader than the old portion to prevent over-topping or seepage.

Removal of Silt Bars from Terrace Channels

To maintain design grade and capacity of the terrace channel silt bars must be removed with such equipment as the bulldozer or scoop. Neglecting to remove bars will cause over-topping, broken terrace ridges, and severe gully erosion below the terrace which failed.

Increasing Terrace Ridge Height

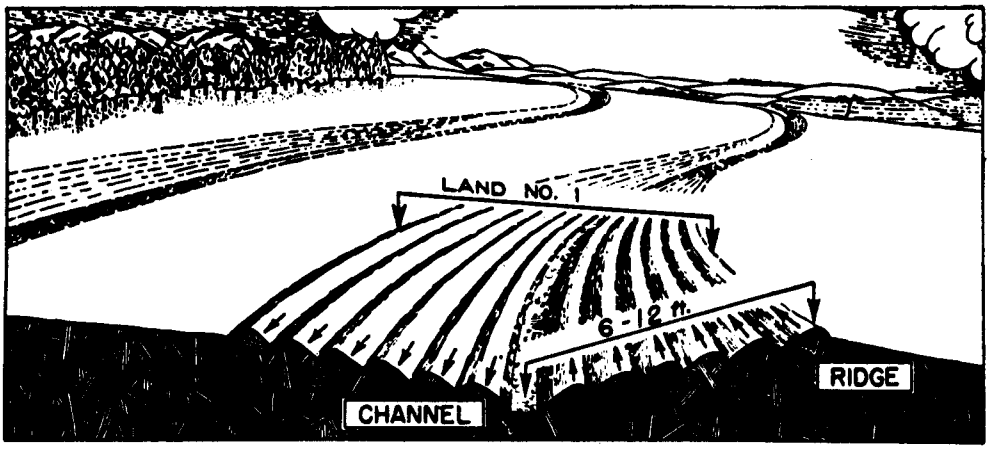
Plowing for Terrace Maintenance. Terraces can be maintained as part of regular plowing operations if the land is plowed. The plowing may be done by one-or-two land method as shown in Figure 4.20. By throwing dirt up or down hill as necessary, the cross section of the terrace can be enlarged or reduced as desired. Some extra work is needed to repair breaks in terrace ridges and some will be required to keep channels open and ridges built up at terrace ends where plowing does not go clear through the full length of the terrace.

In the plowing operation, a strip down the center of the terrace interval may be left for a turn row, so that turns may be made on hard ground during the plowing of irregular areas between terraces. Then the turn row strip may be plowed as a final operation. This is possible where mounted tools can be easily lifted from the ground.

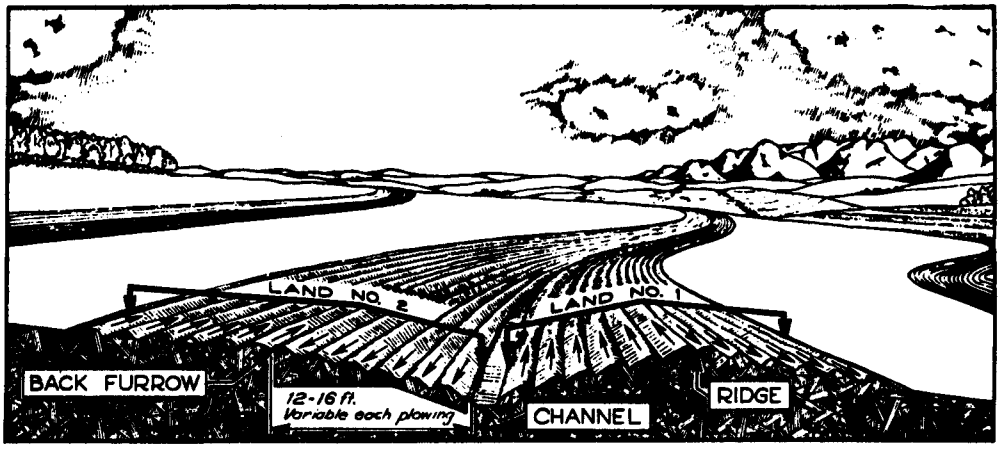
When a one-way disc tiller is used for plowing, the same general procedure for terrace maintenance is used as with a moldboard plow.

If a two-way plow is available, soil may be moved uphill to offset the effect of erosion which carries soil down the slope. Its use will eliminate back-furrows and dead-furrows in undesirable locations and will simplify plowing.

There is less movement of soil down cultivated slopes when fields are in small grain or close-growing crops than when they are in clean-tilled crops. Hence, it is advantageous from the standpoint of terrace maintenance if steep slopes are kept in the former as much as practicable.



ONE-LAND METHOD



TWO-LAND METHOD

Figure 4.20

PLOWING FOR
TERRACE MAINTENANCE

6. TERRACE MAINTENANCE (CONT'D)

Cleaning Channels with Terrace Construction Equipment. When fields are disked or listed rather than plowed it will be necessary to occasionally clean the channels out and build the ridges up with a blade grader or some other tool.

Although it occurs rather infrequently, serious damage may result from washes through the ridge which start from rodent burrows or cracks that are opened up by soil drying. These breaks should be immediately repaired.

7. FARMING TERRACED FIELDS

Preparing Seedbed and Planting Crops on Terraced Land

All seedbed preparation should be carried out by using the terrace as a guide line for starting operations.

Planting Row Crops on Terraced Land

a. Method 1 (See Figure 4.21)

When planting row crops such as corn or sorghum, start planting on the uphill side of the top terrace (Step 1). Don't straddle the terrace with the planter. Put the first row just off the terrace ridge on the uphill side. Continue planting to the top of the slope. Straddling the terrace ridge with the planter will cause trouble later in cultivating - the front shovels will be buried while the rear ones are dangling in the air.

After planting above the top terrace to the edge of the field, continue the planting by starting on the ridge back slope of the top terrace and plant down the slope about one-third of the distance between the first and second terrace (Step 2).

Then go to the channel side of ridge of the second terrace and plant up, just as with the first one, until a strip of land eight rows wide at the narrowest part is left unplanted (Step 3). This remaining area yet to be planted will almost certainly be irregular in width.

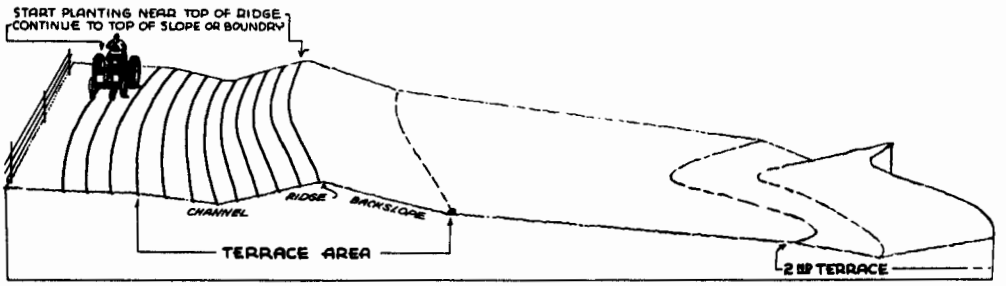
Now plant extra (shorter) rows on the wide portion of this remaining area until the eight row width of turnland extends through the entire length of the field (Step 4). This permits planting the irregular areas without turning on planted ground. This procedure is necessary when planting is done with a lister.

The eight row width turnland is planted last, giving eight rows that go through the entire length of the field (Step 5).

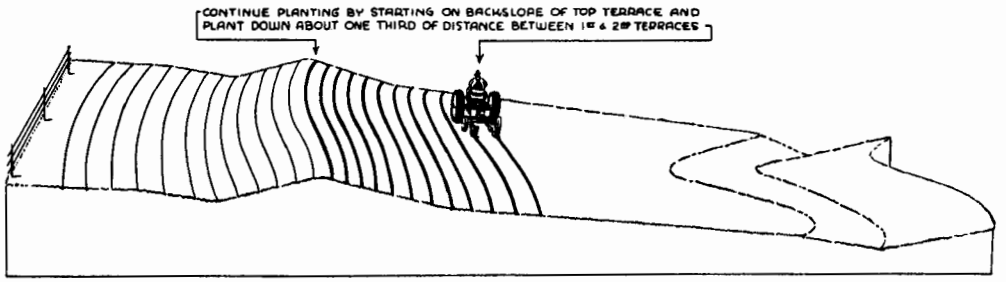
Planting Row Crops on Terraced Land

METHOD No. 1

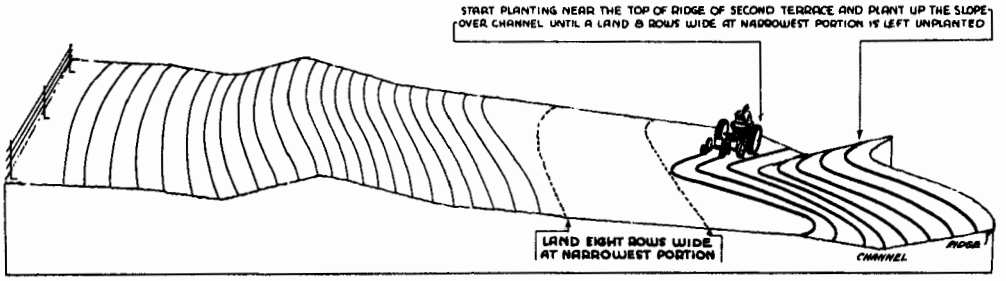
STEP NO. 1



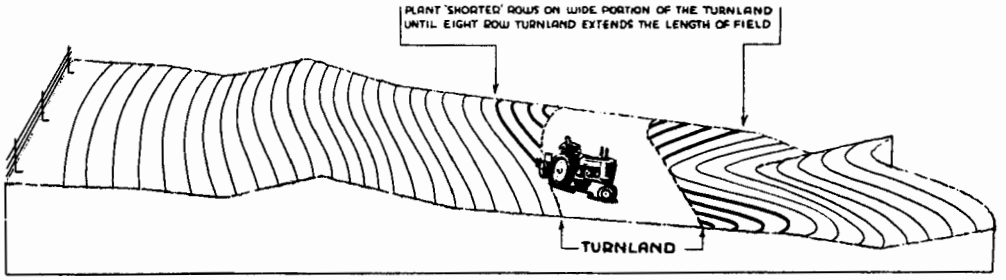
STEP NO. 2


CONTINUE PLANTING BY STARTING ON BACKSLOPE OF TOP TERRACE AND
PLANT DOWN ABOUT ONE THIRD OF DISTANCE BETWEEN 1ST & 2ND TERRACES

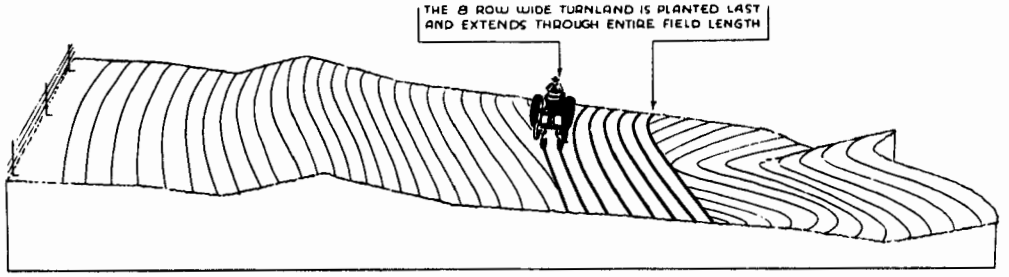
STEP NO. 3


START PLANTING NEAR THE TOP OF RIDGE OF SECOND TERRACE AND PLANT UP THE SLOPE
OVER CHANNEL UNTIL A LAND 8 ROWS WIDE AT NARROWEST PORTION IS LEFT UNPLANTED
LAND EIGHT ROWS WIDE
AT NARROWEST PORTION
CHANNEL
RIDGE

STEP NO. 4



STEP NO. 5



From USDA, SCS
Milwaukee, Wisc.

Figure 4.21

7. FARMING TERRACED FIELDS (CONT'D)

Planting Row Crops on Terraced Land (cont'd)

The width of this turnland may vary but eight rows are enough for either a two row or four row planter.

Many prefer this method because no turning is done on planted ground, and a better contour is maintained. In harvesting pick the eight turn rows and disk them down. This leaves a turning area for picking the point rows.

b. Method 2 (See Figure 4.22)

Another method is to start planting on the channel back slope of the top terrace and continuing to the top of the slope or field boundary (Step 1).

Then start planting on the channel side of the ridge of the second terrace. Plant uphill until a land eight rows wide at the narrowest portion is left unplanted on the back slope of the next terrace above (Step 2).

The remaining area yet to be planted will be irregular in width. Next, plant extra (shorter) rows on the wide portions of the remaining area. This will leave an eight row width of turnland extending through the entire length of the field (Step 3). Here again this permits the irregular areas to be planted without turning on the planted ground.

The final operation is that of planting the turnland. To do this start near the top of the ridge back slope of the top terrace and plant down eight rows (Step 4). The only difference between this method and the first is in location of turnland. In this method the eight row turnland is left just below each terrace instead of halfway between terraces.

Many farmers prefer this method because:

(1) It can be carried out without turning the equipment on planted ground. This is of considerable importance if you plant your corn with a lister.

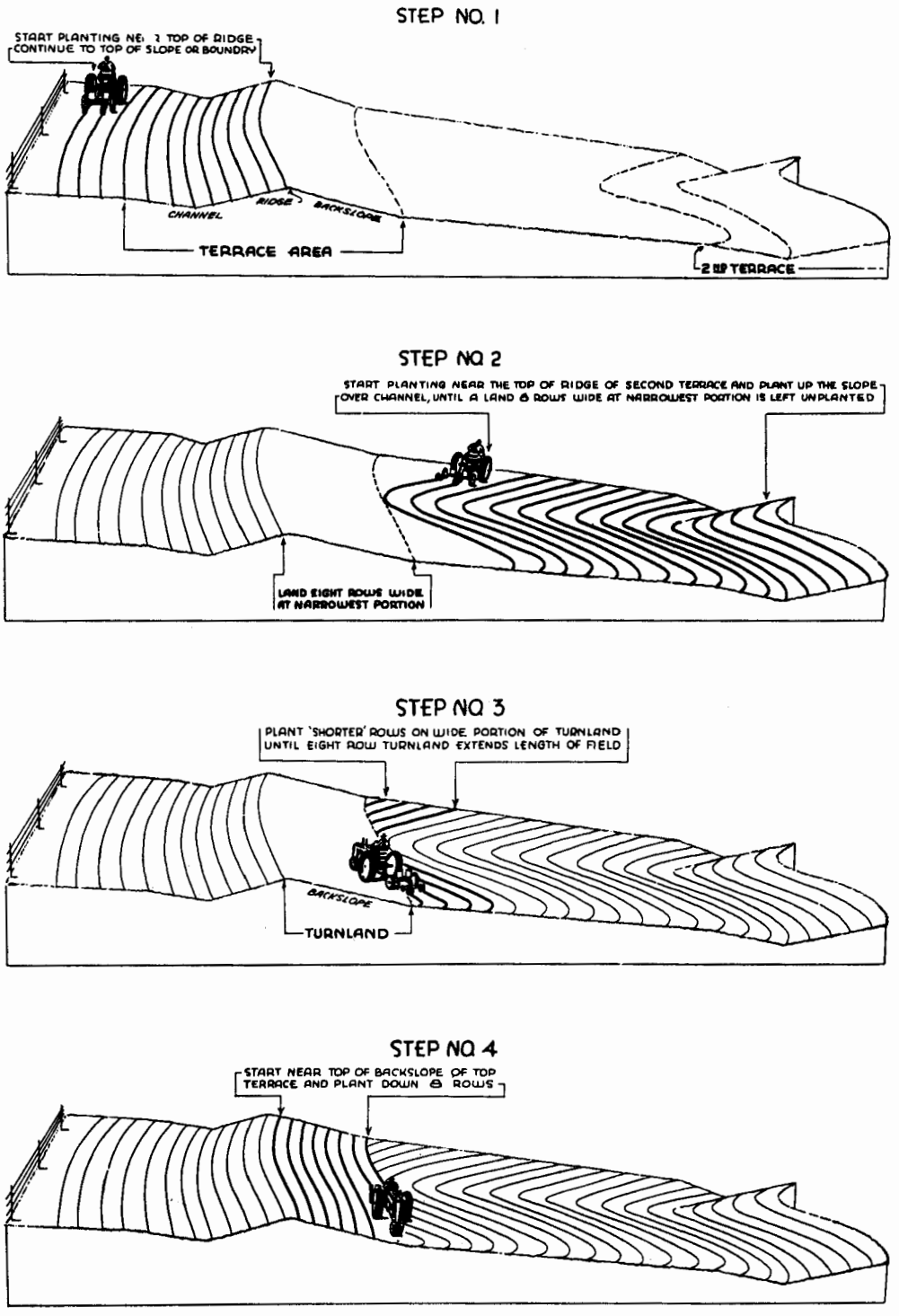
(2) Many farmers find this method of planting easier to explain and more easily understood by the hired man.

(3) With the eight row turnland area located on the back slope of the terrace it is easier to start picking on rows that extend the entire length of the field.

The establishing of the eight row turnland area in both methods 1 and 2 of planting is easily done by eye after a little experience in doing it. Here, as in plowing, it may be desirable

Planting Row Crops on Terraced Land

METHOD No. 2


STEP NO. 1
START PLANTING NEAR TOP OF RIDGE CONTINUE TO TOP OF SLOPE OR BOUNDRY
CHANNEL
RIDGE
BACKSLOPE
TERRACE AREA
2 UP TERRACE
STEP NO 2
START PLANTING NEAR THE TOP OF RIDGE OF SECOND TERRACE AND PLANT UP THE SLOPE OVER CHANNEL, UNTIL A LAND 8 ROWS WIDE AT NARROWEST PORTION IS LEFT UNPLANTED
LAND EIGHT ROWS WIDE AT NARROWEST PORTION
STEP NO 3
PLANT 'SHORTER' ROWS ON WIDE PORTION OF TURNLAND UNTIL EIGHT ROW TURNLAND EXTENDS LENGTH OF FIELD
BACKSLOPE
TURNLAND
STEP NO 4
START NEAR TOP OF BACKSLOPE OF TOP TERRACE AND PLANT DOWN 8 ROWS

From USDA, SCS
Milwaukee, Wisc.

Figure 4.22

7. FARMING TERRACED FIELDS (CONT'D)

Planting Row Crops on Terraced Land (cont'd)

to set two lines of stakes the first time the farmer tries it - one line of stakes in the upper side and the other line on the lower side of turnland. With added experience this will not be necessary.

c. Method 3 (See Figure 4.23)

A third way to put in row crops is to start planting (Step 1) on the uphill slope of the top terrace and planting to the top of the slope on field boundary just as in the other methods. Then start on the back slope (Step 2) of the top terrace and plant down to a point approximately one-half the distance to the second terrace.

Next (Step 3), start planting near the top of the channel back slope of the second terrace, planting uphill until the rows join those already planted. This will leave point rows near the center between terraces. (An alternate method of planting point rows is to plant from both sides rather than from one side as shown.) Continue this procedure with the remaining terraces. When planting is completed to the last terrace, use it as a guide line and plant to the bottom of the field. Where listing is done Method 3 is not recommended because of turning on planted ground.

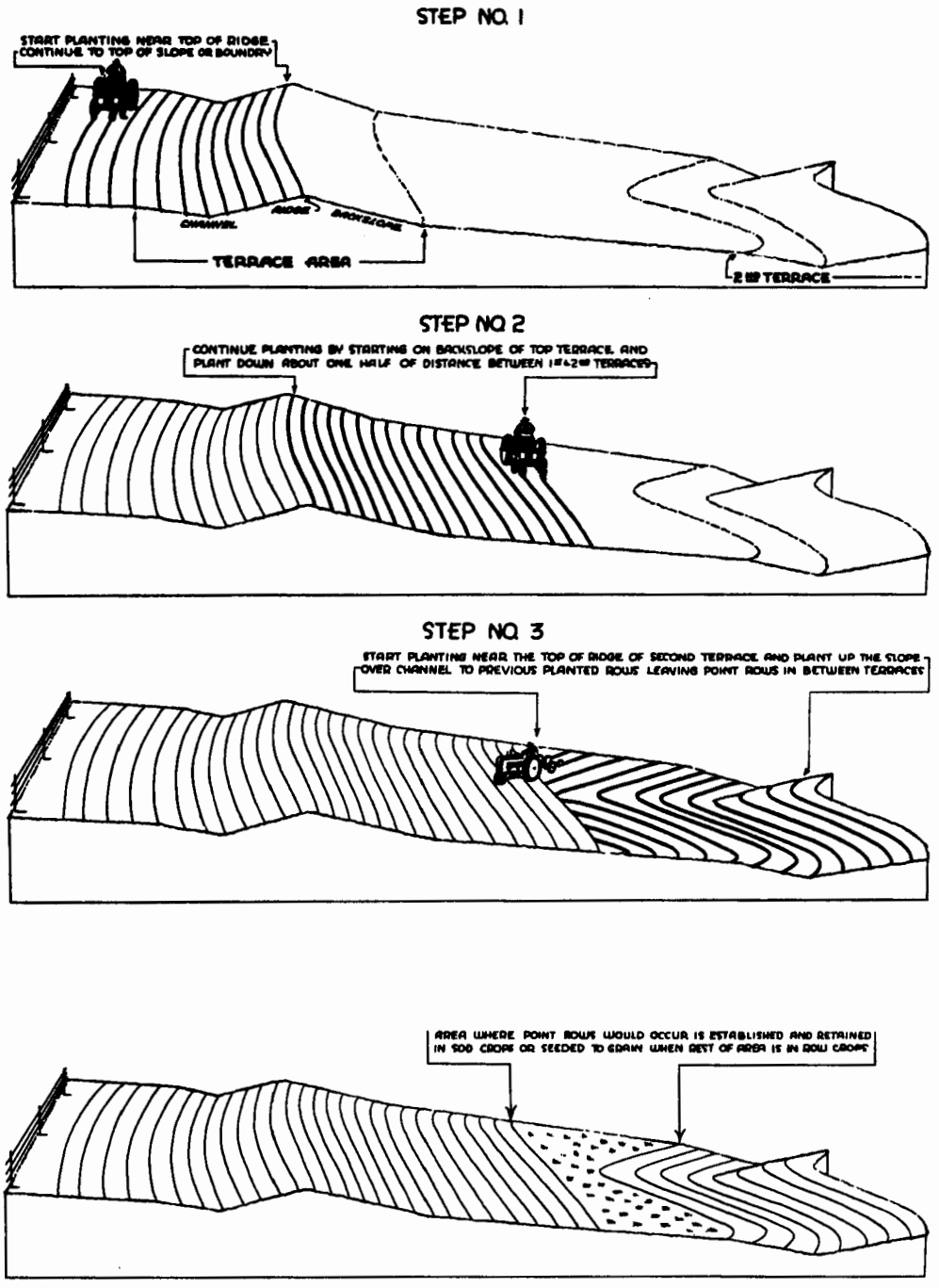
Harvesting Crops on Terraced Land

Harvesting Small Grain (See Figure 4.24) Grain crops will either be harvested with a binder, windrower, or cut direct with a combine. All of these operations present the same general problems. On land that slopes 6 percent or less, standard terraces built according to specifications can be crossed with machinery at almost any angle. The easiest way to harvest grain on such terraces is simply to cut around the field, as would be done if the terraces were not there. On the steeper slopes, where terraces cannot be built wide, it is probably better to harvest the grain with the terraces. If terraces are nearly parallel it would be well to select one key terrace usually near the center terrace. A land can then be opened on this terrace. With a binder or combine this will simply mean back cutting on the terrace ridge selected for a key terrace. With either of these machines it is best to put the grain wheel on the terrace ridge and make a complete round. Self-propelled combines harvest efficiently with the terraces and eliminate most of the harvesting problems.

If a windrower, which delivers the grain to the center, is available, the job is easy since only one back-cut through the field with the windrower is necessary. It is probably better to make this cut with the grain wheel running on the top of the terrace ridge.

Planting Row Crops on Terraced Land

METHOD No. 3


STEP NO. 1
START PLANTING NEAR TOP OF RIDGE CONTINUE TO TOP OF SLOPE OR BOUNDRY
CHANNEL
RIDGE
BACKSLOPE
TERRACE AREA
2 nd TERRACE
STEP NO 2
CONTINUE PLANTING BY STARTING ON BACKSLOPE OF TOP TERRACE AND PLANT DOWN ABOUT ONE HALF OF DISTANCE BETWEEN 1st & 2nd TERRACES
STEP NO 3
START PLANTING NEAR THE TOP OF RIDGE OF SECOND TERRACE AND PLANT UP THE SLOPE OVER CHANNEL TO PREVIOUS PLANTED ROWS LEAVING POINT ROWS IN BETWEEN TERRACES
AREA WHERE POINT ROWS WOULD OCCUR IS ESTABLISHED AND RETAINED IN SOD CROPS OR SEEDED TO GRAIN WHEN REST OF AREA IS IN ROW CROPS

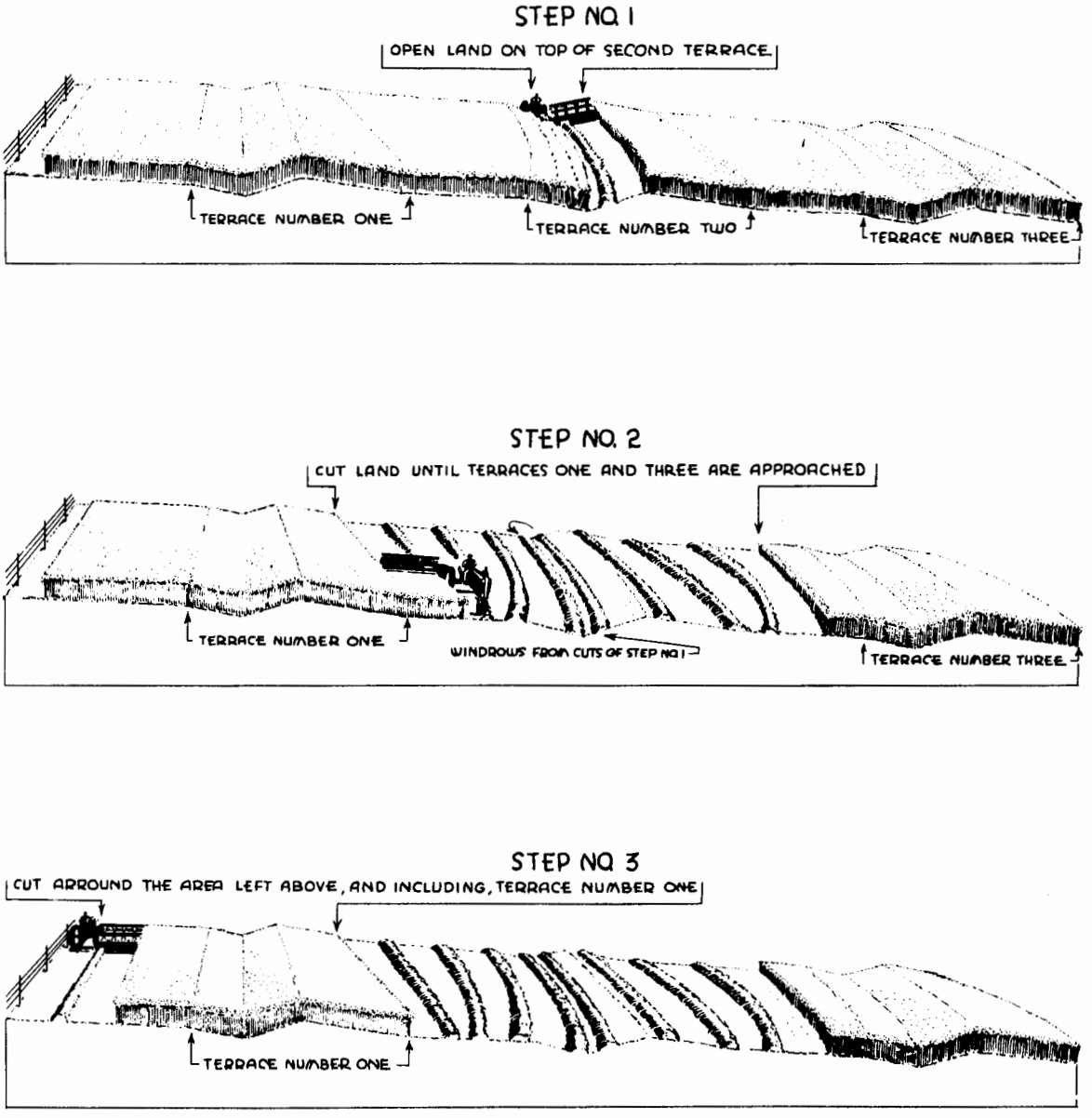
If you don't want to bother with point rows you can just leave the uneven area in meadow or small grain.

From USDA, SCS
Milwaukee, Wisc.

Figure 4.23

SMALL GRAIN

On land that slopes less than about 6 percent terraces are built wide enough to let you cross them with machinery at almost any angle you choose. Thus you can cut such fields by going 'round and 'round them just as you always do. On steeper slopes, where terraces can't be built wide, it is probably better to harvest the grain with the terraces. The three drawings below showing a windrower in operation illustrate how this may be done.


STEP NO. 1
OPEN LAND ON TOP OF SECOND TERRACE
TERRACE NUMBER ONE
TERRACE NUMBER TWO
TERRACE NUMBER THREE
STEP NO. 2
CUT LAND UNTIL TERRACES ONE AND THREE ARE APPROACHED
TERRACE NUMBER ONE
WINDROWS FROM CUTS OF STEP NO 1
TERRACE NUMBER THREE
STEP NO. 3
CUT ARROUND THE AREA LEFT ABOVE, AND INCLUDING, TERRACE NUMBER ONE
TERRACE NUMBER ONE

A METHOD FOR HARVESTING CROPS ON TERRACED LAND (SMALL GRAIN)

Figure 4.24

7. FARMING TERRACED FIELDS (CONT'D)

Harvesting Corn or Grain Sorghum (See Figure 4.25) The method of picking corn on terraced land depends largely on how the field was planted. It will be the reverse, so to speak, of the corn planting procedure. Only one method is shown in detail which is for picking corn planted according to Method 1, Figure 4.24. Others will be very similar and, in any event, will be the reverse of the planting process.

First, open up a land by picking the rows in the eight-row turnland. With a two-row mounted picker this is very simple. With other pickers it will be necessary to contend with down rows.

The short or point rows should be picked next (Step 2). They can be picked very easily by using the eight-row turnland to provide a place to turn equipment.

Next, as illustrated in Step 3, harvest all the long rows between the turnland and terrace number 2. As in the harvesting of the short rows, the eight-row turnland will furnish an adequate turnland for harvesting these rows.

The last step illustrated will be to harvest the rows up to and above the top terrace. Usually it is better to open a land in this area by picking around the area containing the long rows. This is illustrated in Step 4. After the long rows are harvested any short rows that remain along the field boundary can be harvested as a land by working around the remaining corn. By harvesting the long rows first, adequate turning area is provided for picking these short rows.

The remainder of the terraces are harvested as indicated in Steps 1, 2, and 3, and the area below the last terrace can be harvested by lands as is done in picking an ordinary field. It is well here, as in picking out the top terrace, to pick the long rows first, so that adequate turnlands are provided for harvesting the short rows.

Some details which apply to corn harvest in terraced fields in general are:

(1) The method of adapting picking to the various planting methods is to study the charts for planting and use the reverse order.

(2) On all methods of planting, harvest the long rows first. This leaves a good-sized area of picked corn to turn on in harvesting the short rows.

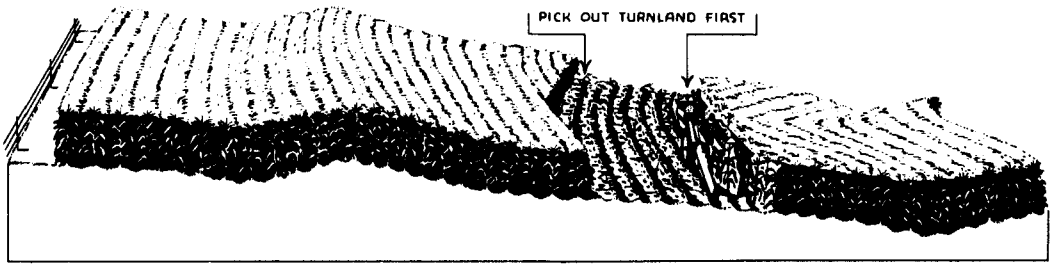
(3) Where a mounted picker is used and the wagon is pulled behind the tractor, wide sideboards will be needed so that corn will not fall on the ground.

(4) On the mounted type picker a shut-off of the elevator should be provided for short curves.

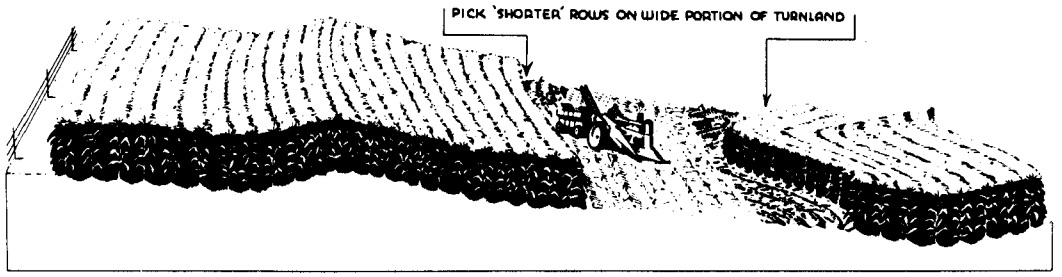
CORN

Harvest row crops in reverse of the way the field was planted. The illustrations below show how to harvest corn where the turnland was planted between the terraces.

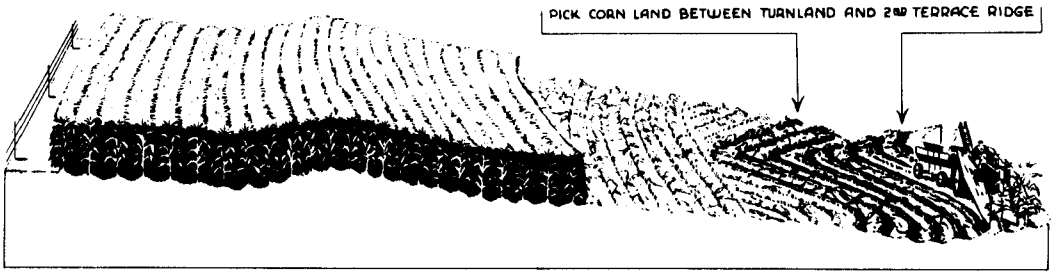
STEP NO. 1



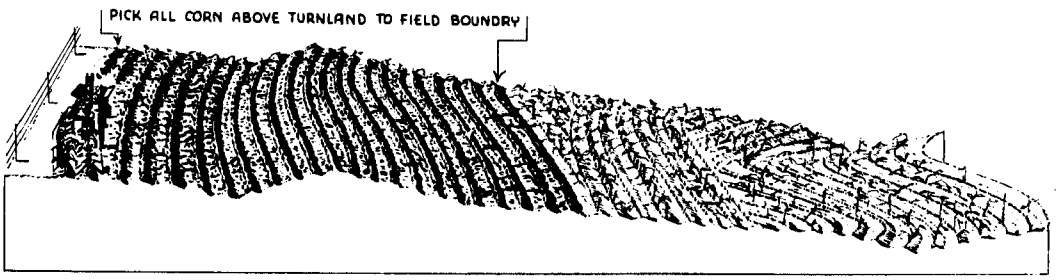
STEP NO 2



STEP NO 3



STEP NO 4



A METHOD FOR HARVESTING CROPS ON TERRACED LAND (CORN)

Figure 4.25

7. FARMING TERRACED FIELDS (CONT'D)

Harvesting Corn or Grain Sorghum (cont'd)

(5) The procedures for harvesting corn for silage can follow the same steps as for picking corn.

Harvesting Hay. Techniques used in cutting hay are similar to those used with grain. On land sloping up to about 6 percent, hay should be cut just as though the field were not terraced. On steeper land it will be better to open up lands on the terraces and work each terrace as an individual unit. Using a side delivery rake presents the most difficult problem. The best starting position is to work the hay down from the top of the terrace ridge. This will leave one windrow in the bottom of the terrace channel and one on the ridge back slope. Both of these are easily picked up with a hay loader. If the short windrows are made and picked up in connection with the last long windrow, much excess driving in the field will be avoided.

GPO 853874

CONTENTS

PART 5

VEGETATED OUTLETS AND WATERWAYS

Subject	Page
1. General	5-1
Definition	5-1
Adaptability of Vegetated Outlets and Waterways	5-1
Types of Vegetated Outlets and Waterways	5-1
Location of Vegetated Outlets and Waterways	5-1
Natural Draws	5-1
Side Field and Ridge Lines	5-2
2. Surveys	5-2
Watershed Map for Planning	5-2
Profile and Cross Sections	5-2
3. Design	5-2
Required Data for Design	5-2
Non-Erosive Velocity of Flow	5-3
Design Storm Frequency	5-4
Vegetative Retardance Factors	5-4
The Waterway-Drainage Channel Combination	5-4
With Permanent Trickle Channel	5-4
With Tile Drain	5-26
With Open Ditch Drainage	5-26
Sloping of Overfalls in Grassed Waterways	5-26
4. Layout	5-28
Staking for Waterway Shaping	5-28
5. Construction	5-28
Waterway Shaping	5-28
With Farm Equipment	5-28
With Heavy Grading Equipment	5-28
Saving the Topsoil	5-35
Establishing Vegetation	5-35
6. Maintenance	5-36
7. Equipment	5-36

LIST OF FIGURES

PART 5

VEGETATED OUTLETS AND WATERWAYS

Figure Number	Title	Page
5.1	Trapezoidal Waterway Dimension Chart Vegetative Retardance A	5-5 & 5-6
5.2	Trapezoidal Waterway Dimension Chart Vegetative Retardance B	5-7 & 5-8
5.3	Trapezoidal Waterway Dimension Chart Vegetative Retardance C	5-9 & 5-10
5.4	Trapezoidal Waterway Dimension Chart Vegetative Retardance D	5-11
5.5	Parabolic Waterway Dimension Chart Vegetative Retardance A	5-12 & 5-13
5.6	Parabolic Waterway Dimension Chart Vegetative Retardance B	5-14 & 5-15
5.7	Parabolic Waterway Dimension Chart Vegetative Retardance C	5-16 & 5-17
5.8	Parabolic Waterway Dimension Chart Vegetative Retardance D	5-18
5.9	Triangular Waterway Dimension Chart Vegetative Retardance A	5-19
5.10	Triangular Waterway Dimension Chart Vegetative Retardance B	5-20
5.11	Triangular Waterway Dimension Chart Vegetative Retardance C	5-21
5.12	Triangular Waterway Dimension Chart Vegetative Retardance D	5-22
5.13	Permissible Velocities for Channels Lined with Vegetation	5-23
5.14	Manning's "n" Related to Velocity, Hydraulic Radius, and Vegetative Retardance	5-24
5.15	Classification of Vegetative Covers as to Degree of Retardance	5-25
5.16	Corrugated Metal Pipe Outlet on Drain Tile	5-27
5.17	Construction of Vegetated Outlets and Waterways	5-29
5.18	Construction of Vegetated Outlets and Waterways	5-30
5.19	Construction of Vegetated Outlets and Waterways	5-31
5.20	Construction of Vegetated Outlets and Waterways	5-32
5.21	Construction of Vegetated Outlets and Waterways	5-33
5.22	Construction of Vegetated Outlets and Waterways	5-34

PART 5

VEGETATED OUTLETS AND WATERWAYS

1. GENERAL

Definition

A constructed or shaped open earth channel which is protected from scour and gully erosion by the establishment of suitable vegetation.

Adaptability of Vegetated Outlets and Waterways

The grassed waterway is one of the most common and basic conservation practices generally recognized, accepted, and practiced by the farmer. Whenever there is rainfall, there are conditions under which a surplus of water will pass over the land in the form of runoff. The success of any soil conservation program depends on the removal of this surplus water without damage to the land.

The safe removal of surplus water is a problem common to every farm. The accumulated flow from only a few acres is sufficient to cause movement of soil to the extent that a gully is started. The need for a protected channel to transport concentrated runoff without damage to the land is obvious.

Types of Vegetated Outlets and Waterways

Vegetated waterways are required as a part of the conservation treatment of practically all farms where water disposal is a problem. There are two types of vegetated waterways - those built in natural channels and those built in artificial channels. Natural channels are used unless gullying has occurred to the extent that it is not feasible to move the earth required to produce a proper cross section. Natural channels usually provide lower and more uniform grades and have the distinct advantage of providing natural drainage for water that is directed into them. No levees or dikes are required to keep the flow in the natural channel. Experience has shown that artificial channels, commonly called "field side outlets" are difficult to maintain, particularly in areas susceptible to wind erosion, usually require removal of earth to the extent that a poor seed bed is produced, and the site location is governed by the field boundary location rather than by topographic considerations.

Location of Vegetated Outlets and Waterways

Natural Draws. In general, the most satisfactory location is in a natural watercourse. Here the slope of the channel is usually the flattest in the watershed. Natural land slope confines the flow; is, in effect, like sideboards, and eliminates the need for levees. Soil and moisture usually are most favorable to vegetative growth. This location interferes less with operations when it is necessary to cross the outlet.

The shape of the natural draw normally is parabolic and a minimum of shaping is necessary.

1. GENERAL (CONT'D)

Location of Vegetated Outlets and Waterways (cont'd)

Side Field and Ridge Lines. It is sometimes necessary to locate the waterway parallel to a fence line or along a ridge. In these instances, it is necessary to construct an artificial channel. Such locations are sometimes used to:

1. Eliminate an outlet in the central part of a field.
2. Outlet terraces or diversions that cannot be extended to a natural draw.
3. Provide an outlet away from buildings or other critical areas.
4. Avoid using a natural draw which has a gully that would be expensive or impractical to control.

2. SURVEYS

Watershed Map for Planning

Terraces or diversions will normally change the surface drainage pattern. For this reason, it is necessary to know approximately the final layout before estimating the amount of runoff the outlet will be required to handle. It is essential that a determination of additional area from terraces or diversions, which will be diverted into a waterway, be made before trying to estimate the runoff.

The watershed map can be completed after changes in normal surface watershed pattern are determined. Usually the natural watershed divides can be determined by field inspection and sketched on the aerial photo map.

Profile and Cross Sections

The original ground surface is profiled and cross sectioned in enough detail to divide the waterway into reaches of approximately uniform slope and shape. The designed cross section dimensions and elevation are superimposed upon the original cross sections to determine the best adapted type of outlet, a balance between cut and fill dirt, and uniform non-erosive velocity.

3. DESIGN

Required Data for Design

The following information is used to design the waterway:

3. DESIGN (CONT'D)

Required Data for Design (cont'd)

1. Runoff, determined from:
   (a) Watershed area in acres
   (b) Soil characteristics
   (c) Land treatment
   (d) Crops
   (e) Topography
   (f) 10-year frequency storm

2. Slope (grade) of waterway.

3. Permissible non-erosive velocity (selected from Figure 5.13).

4. Vegetative retardance factor (see in narrative below).

The tables of waterway dimensions, Figures 5.1 through 5.12, have been prepared from basic hydraulic data to eliminate time-consuming steps and calculations by field men. You will note the tables can be used for the design of the parabolic, trapezoidal, or triangular cross section.

Non-Erosive Velocity of Flow

The design of a waterway is the determination of channel dimensions so that the estimated flow will be discharged without damage to the channel or the lining. The lining considered here is vegetation, which can vary as to type and density. The speed (velocity) at which water can flow safely over each condition is a matter of test and experience.

The prevailing range of velocity in use for design is from three to seven feet per second. Range of maximum permissible velocity will be determined by individual conditions:

1. A velocity of three feet per second will apply to a poor type of sod where, because of climate or soil, only a sparse cover can be expected.

2. A velocity of four feet per second should be used under normal conditions where the waterway is to be established by seeding.

3. A velocity of five feet per second should be used only in areas where vigorous sod is quickly obtained or where water can be diverted out of waterway while seeding is being established.

4. Velocities of six feet per second will be used only when vegetation of good quality is already established or where water can be diverted out of waterway while seeding is being established.

5. Velocities of seven feet per second will be used only on established sod of excellent quality, and only under special circumstances which cannot be handled at a lower velocity. This condition will require special maintenance.

3. DESIGN (CONT'D)

Design Storm Frequency

Waterways are constructed to discharge the flood flow estimated to occur once in 10 years. The cross section may be trapezoidal, triangular, or parabolic. The shape is dictated largely by the nature of the existing topography in the case of natural channels.

Vegetative Retardance Factors

All waterways should be designed in accordance with the principles established in the bulletin "Handbook of Channel Design for Soil and Water Conservation", SCS-TP-61. Figures 5.1 through 5.4, Trapezoidal Waterway Dimension Charts, Vegetative Retardance A, B, C, and D; Figures 5.5 through 5.8, Parabolic Waterway Dimension Charts, Vegetative Retardance A, B, C, and D; and Figures 5.9 through 5.12, Triangular Waterway Dimension Charts, Vegetative Retardance A, B, C, and D, have been prepared in conformance with the general principles outlined in that bulletin. These tables simplify the determination of a waterway size for a given site condition, and generally can be used in lieu of the design procedure outlined in SCS-TP-61, revised June, 1954. In designing grassed waterways, care should be taken to insure that the design velocity is well within the limits of the permissible velocities given in Figure 5.13*. The studies show that the coefficient "n" varies for different rates of flow for any one type of vegetation. A relationship is established between the coefficient "n" and the depth and velocity of flow for the types of vegetation studied. The relationship is shown clearly in Figure 5.14*. This relationship is expressed as vegetative retardance and is designated by the letters "A" through "D". The conditions under which the various types of retardance apply are shown in Figure 5.15*. In view of the fact that most of the vegetation used in waterways does not exceed 24 inches in height and is much shorter many times during its life cycle, it is recommended that when designing the channel for stability a retardance not greater than "C" be used. After designing the channel for stability, it then must be designed to accommodate the peak flow under conditions where vegetation is at maximum growth, as this is the condition giving the highest coefficient of friction "n". The retardance used in this instance is the retardance factor assigned to the vegetation used, and in most cases is retardance "B".

The Waterway Drainage Channel Combination

With Permanent Trickle Channel. Waterways, to be effective, must not be subjected to low flows of long duration or kept wet for long periods because of the existence of a high water table. A tile drainage system may be required to lower a high water table to the point where vegetation will stabilize the channel. Experiments are being conducted to determine the effectiveness of a small permanent type trickle channel constructed in the low point of a vegetated channel which will carry the low rates of flow and thus protect the vegetation so it can safely discharge the larger infrequent flows. The channel can be constructed of monolithic concrete

*Taken from SCS-TP-61

TRAPEZOIDAL WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "A"

Drain Area Acres	Q cfs	Slope = 0.5%												Slope = 1.0%												Slope = 2.0%											
		d=2.4'		d=2.6'		d=2.8'		d=3.0'		d=3.2'		d=3.4'		d=2.0'		d=2.2'		d=2.4'		d=2.6'		d=2.8'		d=3.0'		d=1.8'		d=2.0'		d=2.2'		d=2.4'		d=2.6'			
		b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v		
	10													3	0.47	1	0.47									2	0.46										
	20	10	0.24	7	0.43	5	0.44	3	0.44	1	0.45			9	0.58	7	0.58	4	0.60	3	0.60					5	0.38	3	0.38	2	0.87						
	30	16	0.50	13	0.49	10	0.50	8	0.51	6	0.50	4	0.49	15	0.64	12	0.66	9	0.71	6	0.72	4	0.73	2	0.74	8	1.08	6	1.09	4	1.09	2	1.10				
	40	22	0.53	18	0.53	15	0.55	11	0.57	9	0.57	8	0.56	21	0.69	16	0.74	11	0.83	8	0.85	5	0.86	3	0.89	11	1.23	8	1.23	5	1.28	3	1.33				
	50	27	0.57	23	0.58	18	0.61	14	0.64	11	0.66	10	0.63	26	0.74	19	0.82	13	0.93	9	0.97	7	0.99	4	1.02	13	1.38	9	1.38	7	1.46	4	1.58				
	60	32	0.61	26	0.63	21	0.66	16	0.70	12	0.76	11	0.72	30	0.79	21	0.91	15	1.04	10	1.11	8	1.13	5	1.16	15	1.51	10	1.54	8	1.62	4	1.79				
	70	35	0.65	29	0.69	24	0.71	18	0.77	13	0.85	12	0.30	34	0.84	23	1.01	16	1.15	11	1.24	8	1.28	6	1.30	17	1.63	12	1.78	9	1.79	5	1.97				
	80	39	0.69	31	0.74	26	0.76	20	0.85	14	0.93	13	0.89	37	0.89	24	1.11	17	1.25	12	1.36	9	1.40	7	1.43	19	1.72	13	1.92	10	1.94	6	2.15				
	90	41	0.74	33	0.81	28	0.81	20	0.93	15	1.01	13	0.98	40	0.95	25	1.20	18	1.35	13	1.47	10	1.52	7	1.55	20	1.82	14	2.05	11	2.11	7	2.31	5	2.25		
	100	43	0.80	34	0.87	30	0.87	21	1.00	16	1.09	14	1.07	42	1.00	27	1.28	19	1.45	14	1.58	11	1.64	8	1.68	22	1.90	15	2.16	12	2.23	7	2.47	6	2.42		
	120	45	0.91	36	1.00	32	0.98	23	1.15	18	1.23	15	1.24	46	1.11	29	1.43	21	1.62	16	1.76	12	1.85	9	1.88	25	2.06	17	2.36	13	2.48	9	2.73	7	2.71	23	2.52
	140	48	1.00	38	1.12	34	1.11	25	1.27	19	1.37	16	1.38	50	1.21	32	1.56	23	1.77	18	1.92	14	2.02	11	2.06	28	2.20	20	2.55	15	2.71	10	2.96	8	2.96	26	2.69
	160	52	1.09	40	1.22	35	1.23	27	1.39	21	1.50	17	1.52	53	1.30	35	1.68	26	1.90	19	2.07	15	2.18	12	2.21	31	2.32	22	2.71	16	2.91	12	3.16	9	3.17	29	2.84
	180	55	1.16	42	1.32	37	1.33	28	1.49	23	1.59	19	1.65	56	1.40	37	1.77	28	2.01	21	2.20	17	2.32	13	2.37	34	2.43	24	2.85	18	3.08	13	3.33	10	3.36	32	2.97
	200	59	1.21	44	1.41	39	1.43	30	1.58	24	1.70	20	1.74	59	1.48	40	1.86	30	2.12	23	2.31	18	2.45	15	2.51	37	2.54	26	2.97	20	3.21	14	3.47	11	3.53	34	3.08
	240	67	1.31	50	1.53	43	1.59	34	1.75	27	1.87	23	1.92	66	1.61	46	2.00	34	2.29	27	2.51	21	2.65	17	2.73	42	2.70	30	3.17	23	3.45	17	3.73	14	3.81	40	3.26
	280	76	1.36	56	1.62	47	1.72	37	1.89	31	2.01	26	2.06	74	1.71	51	2.11	38	2.44	30	2.67	24	2.83	20	2.93	47	2.85	34	3.33	26	3.56	20	3.94	16	4.05	45	3.40
	320	87	1.38	62	1.70	52	1.83	41	2.01	34	2.14	30	2.18	83	1.75	57	2.22	42	2.56	34	2.80	27	2.98	23	3.08	53	3.00	38	3.46	29	3.82	23	4.12	19	4.24	51	3.51
	360	99	1.39	70	1.72	57	1.89	45	2.10	38	2.24	33	2.28	93	1.79	62	2.30	47	2.67	37	2.91	30	3.11	25	3.22	58	3.05	42	3.58	33	3.92	26	4.26	21	4.41	56	3.61
	400	110	1.39	78	1.74	62	1.95	49	2.18	41	2.33	36	2.37	102	1.81	68	2.37	51	2.76	41	3.01	33	3.21	28	3.33	64	3.13	46	3.68	36	4.07	28	4.39	23	4.57	61	3.69
	440	122	1.40	86	1.75	68	1.98	53	2.25	44	2.41	39	2.78	112	1.83	73	2.43	55	2.83	44	3.09	36	3.30	31	3.43	69	3.20	51	3.79	39	4.18	31	4.49	26	4.67	67	3.76
	480	133	1.40	95	1.75	75	1.99	57	2.31	48	2.46	42	2.53	122	1.85	79	2.49	59	2.90	48	3.18	39	3.39	33	3.52	75	3.26	55	3.82	42	4.26	34	4.59	28	4.81	72	3.32
	520	145	1.40	104	1.75	82	1.99	61	2.37	52	2.51	46	2.57	131	1.87	84	2.54	64	2.96	51	3.25	43	3.46	36	3.60	80	3.31	59	3.89	46	4.34	37	4.67	30	4.90	78	3.87

Drain Area Acres	Q cfs	Slope = 3.0%										Slope = 4.0%									
		d=1.6'		d=1.8'		d=2.0'		d=2.2'		d=2.4'		d=1.4'		d=1.6'		d=1.8'		d=2.0'		d=2.2'	
		b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
	10											4	0.75	1	0.81						
	20	6	1.02	4	1.02	2	0.99					9	1.07	4	1.25	2	1.25				
	30	8	1.28	6	1.29	3	1.32	2	1.31			10	1.34	7	1.56	3	1.67	1	1.61		
	40	10	1.49	7	1.52	4	1.63	2	1.64			13	1.56	7	1.92	4	2.00	2	1.76		
	50	13	1.65	9	1.74	5	1.89	3	1.94	1	1.93	15	1.77	9	2.07	5	2.31	3	2.27	1	2.27
	60	14	1.80	10	1.94	6	2.16	4	2.20	2	2.19	17	1.94	10	2.26	6	2.56	4	2.56	2	2.60
	70	16	1.94	11	2.11	7	2.38	4	2.43	2	2.45	18	2.01	11	2.46	7	2.80	5	2.80	2	2.84
	80	18	2.07	12	2.29	8	2.58	5	2.65	3	2.67	20	2.25	13	2.62	8	3.00	5	3.05	3	3.11
	90	19	2.18	13	2.45	8	2.76	6	2.86	4	2.86	21	2.39	14	2.78	8	3.21	6	3.28	4	3.33
	100	23	2.52	15	2.95	9	3.39	6	3.47	4	3.55										
	120	26	2.73	17	3.22	11	3.68	8	3.82	5	3.90										
	140	29	2.91	19	3.43	13	3.93	9	4.09	6	4.21										
	160	32	3.06	21	3.62	14	4.13	10	4.37	7	4.49										
	180	35	3.17	23	3.78	16	4.31	12	4.55	9	4.70										
	200	38	3.28	25	3.93	18	4.46	13	4.74	10	4.89										
	240	44	3.45	30	4.14	21	4.73	16	5.04	12	5.24										
	280	50	3.60	34	4.33	24	4.94	18	5.30	14	5.53										
	320	56	3.72	38	4.48	28	5.11	21	5.51	16	5.77										
	360	62	3.81	42	4.61	32	5.12	24	5.68	19	5.97										
	400	68	3.89	47	4.71	34	5.37	26	5.83	21	6.14										
	440	74	3.95	51	4.79	37	5.48	29	5.95	23	6.27										
	480	80	4.01	55	4.86	41	5.57	32	6.06	25	6.38										
	520	96	4.05	60	4.93	44	5.63	34	6.15	28	6.49										

Note: To interpolate on this chart use a straigt line ratio between the respective discharges. Example

Slope = 3% d = 2.0'
Find b & v for Q = 190 cfs
10/20 = .50 this is the proportional part of increment between the respective discharges.
b = 17 - 15 = (2 x .50) + 15 = 16'
v = 3.98 - 3.85 = (.13 x .50) + 3.85 = 3.91 fps

Find "b" & "v" for Slope = 2.6%, d = 2.0' Q = 280 cfs.

Slope = 3%	Slope = 2%
b = 34	b = 23
v = 3.33	v = 4.46

For Slope = 2.6%, b = 34 - 23 = 11', .6 x 11 = 6.6'
b = 23 + 6.6 = 29.6
v = 4.46 - 3.33 = 1.13, 1.13 x .6 = .669
v = 4.46 - .70 = 3.76 fps

d = design flow depth
D = d + 0.5' freeboard
T = constructed top width
t = b + 8d
D = constructed depth
T = b + 8D
b = bottom width from table

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)
2/ Approaching Critical Discharge
3/ Max. Bottom Width (arbitrary) Approx. 300'

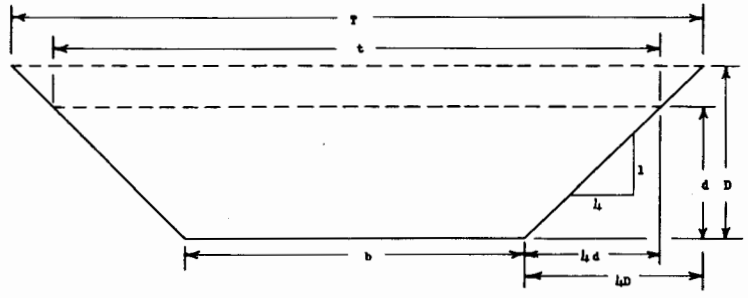


Figure 5.1

TRAPEZOIDAL WATERWAY DIMENSION CHART

VEGETATIVE RESISTANCE "A"

Drain Area Acres	Q cfs	Slope = 5%										Slope = 6%									
		d=1.2		d=1.4		d=1.6		d=1.8		d=2.0		d=1.0		d=1.2		d=1.4		d=1.6		d=1.8	
		b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
	10	5	0.85	2	0.90							8	0.83	4	1.00	2	0.93				
	20	11	1.03	6	1.85	4	1.26	1	1.35			16	1.02	8	1.30	5	1.34	2	1.48		
	30	16	1.23	8	1.54	5	1.72	2	1.81			21	1.20	12	1.53	7	1.77	3	1.99	2	1.81
	40	18	1.43	11	1.77	6	2.01	3	2.17	1	2.22	26	1.35	14	1.77	8	2.10	5	2.29	3	2.29
	50	21	1.61	12	2.06	7	2.29	4	2.48	2	2.55	30	1.49	16	2.00	10	2.36	6	2.52	3	2.72
	60	23	1.79	13	2.30	8	2.65	5	2.73	2	2.88	34	1.57	18	2.24	11	2.58	7	2.79	4	2.97
	70	26	1.92	15	2.48	9	2.91	6	3.06	3	3.18	38	1.66	20	2.35	12	2.84	8	3.14	5	3.18
	80	28	2.06	16	2.64	10	3.14	6	3.36	4	3.47	43	1.70	22	2.48	14	2.99	8	3.47	6	3.49
	90	30	2.15	17	2.81	11	3.23	7	3.52	4	3.68	48	1.74	24	2.60	15	3.12	9	3.65	6	3.78
	100	32	2.26	19	2.95	12	3.45	8	3.72	5	3.90	52	1.78	26	2.70	16	3.30	10	3.81	7	4.05
	120	37	2.39	21	3.19	13	3.78	9	4.11	6	4.28	61	1.84	30	2.87	18	3.71	12	4.18	8	4.38
	140	41	2.54	24	3.42	15	4.03	11	4.39	7	4.66	70	1.84	34	3.04	20	3.90	13	4.51	9	4.80
	160	46	2.65	26	3.60	17	4.27	12	4.58	8	5.00	79	1.93	38	3.15	22	4.14	15	4.71	10	5.07
	180	50	2.73	29	3.73	19	4.42	14	4.96	10	5.14	88	1.96	41	3.27	24	4.34	16	5.02	12	5.26
	200	54	2.83	31	3.89	21	4.61	15	5.05	11	5.40	97	1.99	45	3.34	26	4.52	18	5.12	13	5.50
	240	64	2.92	36	4.09	24	4.87	18	5.35	13	5.71	115	2.02	52	3.52	31	4.68	21	5.37	16	5.87
	280	73	3.01	42	4.24	28	5.08	21	5.51	16	5.78	133	2.05	59	3.65	35	4.92	24	5.75	18	6.17
	320	82	3.07	47	4.38	32	5.26	24	5.79	18	6.20	151	2.07	66	3.76	39	5.12	28	5.89	21	6.30
	360	91	3.13	52	4.50	35	5.39	26	5.97	20	6.42	169	2.08	73	3.88	43	5.29	31	6.01	24	6.51
	400	100	3.19	57	4.60	39	5.50	29	6.13	22	6.60	187	2.09	80	3.93	47	5.43	34	6.18	26	6.69
	440	109	3.23	62	4.64	43	5.62	32	6.23	25	6.70	205	2.11	89	4.01	51	5.55	38	6.26	29	6.84
	480	118	3.27	67	4.72	46	5.70	35	6.34	27	6.85	223	2.11	93	4.08	55	5.65	41	6.32	31	6.98
	520	127	3.30	72	4.79	50	5.76	38	6.39	29	6.85	241	2.12	101	4.09	59	5.74	44	6.44	34	7.01

Drain Area Acres	Q cfs	Slope = 7%										Slope = 8%								Slope = 9%						Slope = 10%					
		d=1.0		d=1.2		d=1.4		d=1.6		d=1.8		d=1.0		d=1.2		d=1.4		d=1.6		d=0.8		d=1.0		d=1.2		d=1.4		d=0.6		d=0.8		d=1.0		d=1.2	
		b	v	b	v	h	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
	10	7	0.90	4	1.00	2	0.93					6	1.00	2	1.17	1	1.08			10	0.93	5	1.15	2	1.19			18	0.83	10	0.98	5	1.06	3	1.07
	20	13	1.16	7	1.46	5	1.41	2	1.58			12	1.29	5	1.66	3	1.72			20	1.08	9	1.56	5	1.67	2	1.79	36	0.88	20	1.06	9	1.52	5	1.75
	30	18	1.38	9	1.79	6	1.84	3	2.10			15	1.57	8	2.00	4	2.18	2	2.34	28	1.21	13	1.82	7	2.08	4	2.28	53	0.90	31	1.09	12	1.84	6	2.27
	40	22	1.55	11	2.09	7	2.30	3	2.55	2	2.55	18	1.63	10	2.29	6	2.57	3	2.74	36	1.29	16	2.02	9	2.45	5	2.75	71	0.91	42	1.10	15	2.13	8	2.67
	50	25	1.71	13	2.31	8	2.66	4	2.94	2	3.01	21	2.04	12	2.54	7	2.95	4	3.15	43	1.35	19	2.18	10	2.80	6	3.13	89	0.91	53	1.12	17	2.36	8	3.26
	60	29	1.83	15	2.52	9	2.97	5	3.28	3	3.43	23	2.21	13	2.77	8	3.24	4	3.52	51	1.39	22	2.32	11	3.09	7	3.51	107	0.92	64	1.12	19	2.58	10	3.33
	70	32	1.96	17	2.73	10	3.24	6	3.61	3	3.81	26	2.34	15	2.99	9	3.54	5	3.80	58	1.44	25	2.44	13	3.35	7	3.85	124	0.92	75	1.13	22	2.75	11	3.62
	80	35	2.04	18	2.92	11	3.50	7	3.97	4	4.15	29	2.46	16	3.17	10	3.78	6	4.09	65	1.47	27	2.55	14	3.58	8	4.14	142	0.92	85	1.13	24	2.91	13	3.85
	90	39	2.10	20	3.08	12	3.71	7	4.13	5	4.27	31	2.55	17	3.37	10	4.04	6	4.39	72	1.50	30	2.65	15	3.79	9	4.37	160	0.92	96	1.13	26	3.05	14	4.08
	100	42	2.16	21	3.22	13	3.92	8	4.34	5	4.55	34	2.63	19	3.54	11	4.27	7	4.62	79	1.52	33	2.74	16	3.97	10	4.61	178	0.92	107	1.13	28	3.17	15	4.27
	120	49	2.27	24	3.47	14	4.28	10	4.68	6	4.97	39	2.77	21	3.83	13	4.60	8	5.06	93	1.56	37	2.91	19	4.27	12	5.01	196	1.01	117	1.24	32	3.38	17	4.61
	140	56	2.34	27	3.66	16	4.56	11	4.94	8	5.29	45	2.87	24	4.05	15	4.87	10	5.43	107	1.59	42	3.06	21	4.52	13	5.32	213	1.08	129	1.33	36	3.54	19	4.88
	160	63	2.40	30	3.83	18	4.80	13	5.06	9	5.66	50	2.95	27	4.24	17	5.10	11	5.74	121	1.61	46	3.18	23	4.73	15	5.60		3/	139	1.36	40	3.68	21	5.11
	180	69	2.45	33	3.96	20	4.98	14	5.51	10	5.91	56	3.02	29	4.41	19	5.27	12	6.01	135	1.63	51	3.28	26	4.90	17	5.82			150	1.47	44	3.99	24	5.28
	200	76	2.50	36	4.08	22	5.13	16	5.70	11	6.10	61	3.08	32	4.55	21	5.45	14	6.25	149	1.65	56	3.36	28	5.05	18	6.03			161	1.52	48	3.88	26	5.45
	240	90	2.56	42	4.27	26	5.37	19	6.02	14	6.44	72	3.15	37	4.78	24	5.71		2/	177	1.67	65	3.50	33	5.29		2/			171	1.71	56	4.03	30	5.71
	280	103	2.61	48	4.41	31	5.54	22	6.27		2/	83	3.21	42	4.96	28	5.91			205	1.68	73	3.60	38	5.48					183	1.88	64	4.15	35	5.92
	320	117	2.65	54	4.53	35	5.68	25	6.47			94	3.26	47	5.10	32	6.07					83	3.69	43	5.63					193	2.03	72	4.24	39	6.07
	360	130	2.68	60	4.62	39	5.83	28	6.63			105	3.30	53	5.22	36	6.21					92	3.76	47	5.75					204	2.17	80	4.31		2/
	400	144	2.71	66	4.70	43	5.91	31	6.77			116	3.33	58	5.32	40	6.32					101	3.81	52	5.85							88	4.37		
	440	157	2.73	72	4.77	47	6.02	34	6.89			127	3.35	63	5.41	43	6.41					110	3.86	57	5.93							96	4.42		
	480	171	2.75	78	4.83	51	6.08	37	6.99			138	3.38	68	5.47	47	6.49					119	3.90	62	6.01							104	4.47		
	520	184	2.76	84	4.87	55	6.14					149	3.39	73	5.54	51	6.56					128	3.93	67	6.07							112	4.50		

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example

Slope = 7% d = 1.6'
Find b & v for Q = 375 cfs
15/40 = .375 this is the proportional part of increment between the respective discharges.
b = 31 - 28 = (3 x .375) + 28 = 29'
v = 6.63 - 6.47 = (16 x .375) + 6.47 = 6.53 fps

Find "b" & "v" for Q = 100 cfs d = 1.2' Slope = 8.4%

Slope 8%	Slope 9%
19	16
3.54	3.97

For Slope 8.4%, 'b' = 19 - 16 = 3
"b" = .4 x 3 = 1.2, b = 19 - 1.2 = 17.8'
v = 3.97 - 3.54 = .43
v = .4 x .43 = .17 + 3.54 = 3.71 fps

d = design flow depth
D = d + 0.5' freeboard
T = constructed top width
t = b + 8d
D = constructed depth
T = b + 8D
b = bottom width from table

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)

2/ Approaching Critical Discharge

3/ Max. Bottom Width (arbitrary) Approx. 300'

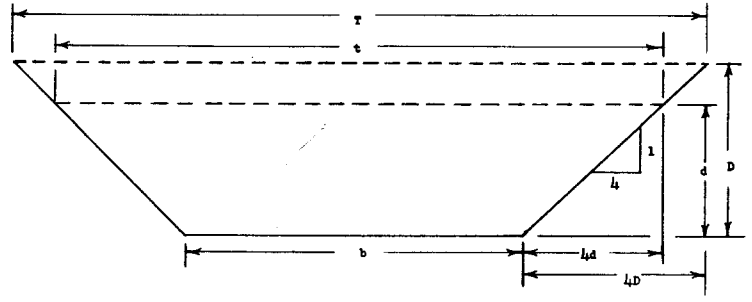


Figure 5.1 (cont'd)

TRAPEZOIDAL WATERWAY DIMENSION CHART

Sheet 1 of 2

VEGETATIVE RETARDANCE "B"

Area Acs.	Q cfs	Slope = 0.5%												Slope = 1.0%																		Slope = 2.0%																		Slope = 3.0%																		Slope = 4.0%																	
		d =1.3'		d =2.0'		d=2.2'		d=2.4'		d=2.6'		d=2.8'		d=1.6'		d=1.8'		d=2.0'		d=2.2'		d =2.4'		d=2.6'										d=1.2'		d=1.4'		d=1.6'		d=1.8'		d=2.0'										d=1.0'		d=1.2'		d=1.4'		d=1.6'		d=1.8'										d=0.8'		d=1.0'		d=1.2'		d=1.4'		d=1.6'	
		b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v							b	v	b	v	b	v	b	v	b	v							b	v	b	v	b	v	b	v	b	v							b	v	b	v	b	v	b	v	b	v
	10	4	0.51	2	0.52	-	-	-	-	-	-	-	-	3	0.70	-	-	-	-	-	-	-	-	-	-							3	1.04	1	1.05	-	-	-	-	-	-							6	1.05	3	1.14	-	-	-	-	-	-							8	1.12	4	1.32	1	1.34	-	-	-	-
	20	7	0.76	5	0.30	3	0.30	1	0.78	-	-	-	-	5	1.09	3	1.12	1	1.11	-	-	-	-	-	-							7	1.43	4	1.51	1	1.60	-	-	-	-							10	1.47	5	1.70	3	1.76	-	-	-	-							13	1.50	7	1.39	3	2.22	1	2.16	-	-
	30	11	0.94	7	1.00	5	1.02	3	1.03	-	-	-	-	8	1.34	5	1.42	3	1.42	-	-	-	-	-	-							10	1.68	6	1.84	3	1.99	1	2.03	-	-							13	1.78	7	2.10	4	2.27	2	2.37	-	-							18	1.73	9	2.31	4	2.91	2	2.82	-	-
	40	14	1.07	9	1.17	6	1.21	4	1.22	2	1.29	-	-	10	1.52	7	1.62	4	1.66	2	1.68	-	-	-	-							12	1.93	8	2.15	4	2.33	2	2.41	-	-							16	2.04	9	2.43	5	2.74	3	2.80	-	-							23	1.90	11	2.63	6	3.24	3	3.32	1	3.39
	50	17	1.17	11	1.30	8	1.35	6	1.37	2	1.51	2	1.40	12	1.69	8	1.80	5	1.92	3	1.92	1	1.96	-	-							15	2.14	9	2.41	6	2.62	3	2.72	1	2.72							18	2.25	10	2.91	6	3.07	3	3.32	1	3.38							28	3.03	13	2.91	7	3.53	4	3.68	2	3.72
	60	19	1.27	14	1.39	10	1.49	7	1.50	5	1.54	3	1.56	14	1.82	10	1.93	7	2.06	4	2.09	2	2.16	-	-							17	2.27	11	2.66	7	2.79	4	2.97	2	3.00							20	2.50	11	3.16	7	3.40	4	3.60	2	3.62							32	2.13	15	3.17	8	3.32	5	3.97	3	4.21
	70	22	1.35	15	1.50	11	1.59	9	1.61	6	1.67	4	1.70	16	1.93	12	2.07	8	2.22	5	2.25	3	2.31	1	2.32							20	2.35	12	2.84	8	3.03	5	3.18	3	3.24							24	2.54	13	3.27	8	3.67	5	3.83	3	4.00							36	2.23	17	3.33	10	4.08	6	4.31	4	4.42
	80	25	1.40	18	1.56	13	1.66	10	1.74	7	1.76	5	1.81	18	2.02	13	2.20	9	2.35	7	2.37	4	2.45	2	2.48							22	2.48	14	2.99	10	3.14	6	3.36	4	3.34							26	2.66	15	3.45	10	3.78	6	4.20	3	4.35							41	2.28	19	3.48	11	4.22	7	4.34	4	4.71
	90	27	1.46	19	1.64	14	1.79	11	1.32	8	1.38	6	1.91	20	2.13	15	2.30	11	2.43	8	2.50	5	2.62	3	2.64							25	2.55	15	3.12	11	3.32	7	3.52	4	3.68							28	2.31	16	3.60	11	3.99	7	4.36	4	4.46							45	2.35	21	3.60	12	4.46	8	4.73	5	5.16
	100	30	1.50	21	1.70	16	1.86	12	1.92	9	1.92	7	2.00	22	2.20	16	2.39	12	2.56	9	2.56	6	2.75	4	2.77							27	2.62	16	3.30	12	3.39	8	3.70	5	3.84							31	2.85	18	3.65	12	4.17	8	4.49	5	4.74							49	2.39	23	3.70	14	4.55	9	4.96	6	5.25
	120	35	1.59	25	1.80	19	1.99	15	2.07	12	2.10	9	2.17	26	2.33	19	2.54	14	2.72	11	2.82	7	2.97	5	2.99							31	2.79	19	3.48	14	3.67	10	3.99	7	4.13							37	2.96	21	3.87	14	4.57	9	4.87	6	5.05							58	2.47	27	3.87	16	4.31	11	5.32	7	5.58
	140	40	1.64	29	1.89	22	2.09	17	2.19	14	2.25	11	2.30	30	2.43	22	2.71	16	2.87	13	2.98	9	3.15	7	3.18							36	2.89	22	3.62	17	3.32	11	4.22	8	4.37							42	3.04	24	4.05	16	4.62	11	5.02	8	5.29							66	2.52	31	4.00	18	5.05	12	5.36	8	5.99
	160	45	1.71	33	1.97	25	2.18	19	2.31	16	2.31	12	2.43	34	2.50	25	2.80	19	3.01	14	3.17	10	3.33	8	3.39							40	2.97	25	3.73	19	4.01	13	4.44	9	4.62							47	3.13	27	4.19	18	4.34	13	5.29	9	5.66							75	2.57	35	4.10	21	5.23	14	5.33	10	6.25
	180	50	1.76	36	2.03	28	2.25	22	2.41	18	2.48	14	2.55	37	2.57	27	2.89	21	3.15	16	3.31	12	3.47	9	3.56							44	3.07	28	3.92	21	4.10	14	4.65	11	4.83							53	3.18	31	4.24	21	4.92	14	5.51	10	5.31							83	2.61	39	4.19	23	5.38	-	-2/	-	-2/
	200	54	1.91	40	2.08	30	2.31	24	2.49	19	2.59	16	2.66	41	2.62	30	2.98	23	3.25	18	3.45	12	3.63	10	3.73							48	3.15	31	3.90	23	4.25	16	4.78	12	5.00							58	3.25	34	4.35	23	5.09	16	5.58	12	5.95							92	2.62	43	4.26	26	5.50	-	-	-	-
	240	64	1.37	47	2.17	36	2.42	28	2.54	23	2.76	19	2.83	49	2.70	36	3.10	27	3.42	21	3.69	16	3.89	13	4.01							57	3.23	37	4.02	28	4.42	19	5.05	15	5.28							68	3.33	40	4.46	27	5.25	20	5.79	14	6.28							109	2.68	52	4.32	30	5.68	-	-	-	-
	280	74	1.91	54	2.25	42	2.50	33	2.73	27	2.87	22	2.99	57	2.78	41	3.20	31	3.57	24	3.35	19	4.07	15	4.22							66	3.29	43	4.15	31	4.67	23	5.23	17	5.53							79	3.37	46	4.59	32	5.39	23	5.95	17	6.42							127	2.69	60	4.41	35	5.83	-	-	-	-
	320	84	1.96	61	2.31	48	2.58	38	2.93	31	3.00	26	3.11	64	2.92	47	3.28	36	3.67	28	4.00	22	4.21	18	4.39							75	3.34	48	4.26	35	4.93	26	5.35	20	5.71							90	3.42	52	4.69	36	5.49	26	6.17	20	6.65							143	2.73	68	4.48	40	5.25	-	-	-	-
	360	94	1.98	68	2.36	53	2.64	42	2.90	34	3.11	28	3.27	72	2.96	53	3.35	40	3.77	31	4.13	25	4.37	20	4.55							84	3.37	54	4.31	39	4.95	29	5.52	23	5.86							100	3.46	59	5.70	41	5.57	30	6.26	-	-2/							161	2.74	76	4.50	45	6.02	-	-	-	-
	400	104	2.00	75	2.40	59	2.70	47	2.97	38	3.17	32	3.34	80	2.90	58	3.40	44	3.84	34	4.22	28	4.48	23	4.67							93	3.40	60	4.35	43	5.06	33	5.57	25	5.98							111	3.47	66	4.74	45	5.64	33	6.34	-	-							178	2.75	84	4.57	50	6.08	-	-	-	-
	440	113	2.03	82	2.44	64	2.71	51	3.01	42	3.26	35	3.43	88	2.92	64	3.45	48	3.92	38	4.31	31	4.57	25	4.78							102	3.43	66	4.38	47	5.14	36	5.72	28	6.17							122	3.62	72	4.77	49	5.75	37	6.41	-	-							195	2.78	91	4.66	55	6.18	-	-	-	-
	480	123	2.04	88	2.49	70	2.76	56	3.04	46	3.30	38	3.52	95	2.95	69	3.49	52	3.98	41	4.39	33	4.66	27	4.89							111	3.45	72	4.44	52	5.18	39	5.77	31	6.21							132	3.63	78	4.83	54	5.75	40	6.46	-	-							212	2.79	97	4.78	60	6.22	-	-	-	-
	520	133	2.06	96	2.51	76	2.80	61	3.09	49	3.36	41	3.57	103	2.97	75	3.52	56	4.03	44	4.47	36	4.74	30	4.98							120	3.48	77	4.49	56	5.25	42	5.37	34	6.26							142	3.66	-	-	-	-	-	-	-	-							229	2.80	100	4.99	-	-	-	-	-	-

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example

Slope = 3% d = 1.4'
Find b & v for Q = 130 cfs
10/20 = .50 this is the proportional part of increment between the respective discharges.
b = 16 - 14 = (2 x .50) + 14 = 15'
v = 4.62 - 4.37 = (.25 x .50) + 4.37 = 4.50 fps

Find "b" & "v" for Q = 200 cfs Slope = 1.6% d = 1.8'

Slope 1%	Slope 2%
"b" = 30'	"b" = 16'
"v" = 2.98'	"v" = 4.78'

For Slope 1.6%, b = 30 - 16 = 14
b = 14 x .6 = 8.4', b = 30.0 - 8.4 = 21.6'
v = 4.78 - 2.98 = 1.80
v = 1.80 x .6 = 1.08, v = 2.98 + 1.08 = 4.06 fps

d = design flow depth
D = d + 0.5' freeboard
T = constructed top width
t = b + 8d
D = constructed depth
T = b + 8D
b = bottom width from table

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)

2/ Approaching Critical Discharge

3/ Max. Bottom Width (arbitrary) Approx. 300'

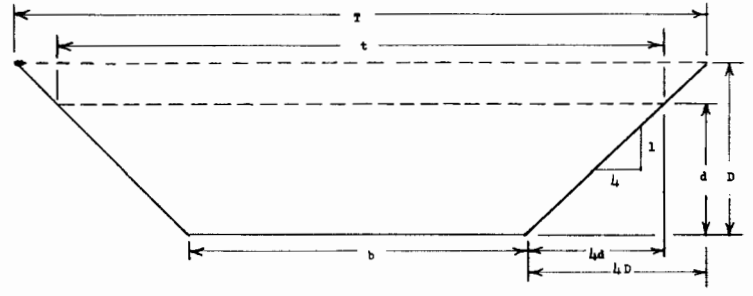


Figure 5.2

Sheet 2 of 2

TRAPEZOIDAL WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "B"

Area Acs.	Q cfs	Slope = 5%										Slope = 6%									
		d=0.8'		d=1.0'		d=1.2'		d=1.3'		d=1.4'		d=0.8'		d=0.9'		d=1.0'		d=1.1'		d=1.2'	
		b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
	10	6	1.40	2	1.56							5	1.50	3	1.33	3	2.00	2	2.00		
	20	10	1.86	5	2.24	2	2.34	1	2.36			8	2.00	6	2.32	4	2.40	3	2.60	2	2.80
	30	14	2.14	7	2.67	4	2.91	3	2.95	2	3.01	12	2.50	8	2.73	6	3.00	4	3.10	3	3.40
	40	18	2.34	9	3.05	5	3.40	4	3.41	3	3.53	15	2.70	10	3.04	8	3.50	6	3.80	4	3.80
	50	22	2.48	11	3.33	7	3.68	5	3.84	3	4.15	18	2.88	13	3.40	9	3.70	7	4.10	5	4.10
	60	26	2.56	13	3.48	8	3.90	6	4.12	4	4.46	21	3.10	15	3.55	11	4.00	8	4.35	6	4.40
	70	30	2.67	15	3.68	9	4.22	7	4.41	5	4.62	24	3.20	17	3.70	12	4.20	9	4.60	7	4.65
	80	33	2.74	17	3.80	11	4.35	8	4.66	6	4.92	27	3.30	19	3.85	14	4.40	11	4.90	8	4.85
	90	37	2.83	19	3.91	12	4.55	9	4.88	7	5.10	30	3.40	21	3.97	16	4.60	12	5.05	10	5.20
	100	40	2.89	21	4.00	13	4.68	10	5.06	8	5.25	33	3.45	23	4.03	17	4.65	13	5.20	11	5.45
	120	47	2.98	25	4.13	15	5.00	12	5.36	10	5.67	39	3.55	28	4.14	20	4.90	16	5.45	12	5.65
	140	54	3.08	29	4.30	18	5.11	13	5.91	11	6.02	45	3.65	32	4.42	23	5.05	18	5.60	14	5.95
	160	61	3.13	32	4.44	20	5.37	16	5.94	-	-2/	51	3.70	36	4.55	26	5.25	20	5.75	16	6.10
	180	67	3.20	36	4.50	23	5.49	-	-2/			57	3.75	39	4.60	29	5.35	23	5.90	2/	
	200	74	3.23	39	4.65	25	5.59					63	3.80	43	4.70	32	5.45	25	6.00		
	240	88	3.28	46	4.80	29	5.91					75	3.85	52	4.85	39	5.60	29	6.10		
	280	102	3.34	53	4.91	33	6.12					87	3.88	59	4.95	45	5.75	34	6.22		
	320	115	3.38	60	5.04	38	6.30					99	3.90	68	5.00	52	5.85	39	6.35		
	360	130	3.39	67	5.10	-	-2/					121	3.91	76	5.03	57	5.90	44	6.40		
	400	144	3.39	74	5.16							147	4.02	83	5.08	63	6.00	49	6.50		
	440	158	3.41	81	5.17							171	4.05	92	5.12	68	6.02	-	-		
	480	172	3.42	87	5.27							195	4.08	100	5.15	76	6.05	-	-		
	520	186	3.43	95	5.27							218	4.10	108	5.18	81	6.08				

Area Acs.	Q cfs	Slope = 7%										Slope = 8%								Slope = 9%								Slope = 10%							
		d=0.6'		d=0.7'		d=0.8'		d=0.9'		d=1.0'		d=0.6'		d=0.7'		d=0.8'		d=0.9'		d=0.6'		d=0.7'		d=0.8'		d=0.9'		d=0.5'		d=0.6'		d=0.7'		d=0.8'	
		b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
	10	11	1.24	7	1.53	4	1.84	3	1.82	2	1.81	9	1.36	4	2.04	3	2.01	2	2.17	9	1.46	5	1.83	3	2.01			15	1.17	9	1.50	5	1.99	3	2.01
	20	20	1.52	12	1.99	8	2.27	5	2.65	4	2.35	16	1.70	9	2.42	6	2.71	4	2.92	16	1.36	9	2.42	6	2.87	3	3.65	27	1.40	14	2.03	7	2.91	5	3.04
	30	27	1.68	16	2.25	11	2.72	7	3.14	5	3.15	21	2.10	13	2.74	9	3.07	6	3.47	22	2.09	12	2.89	8	3.34	5	3.87	37	1.55	19	2.39	11	3.10	7	3.67
	40	36	1.75	21	2.45	13	3.01	9	3.52	7	3.80	27	2.24	16	3.00	11	3.49	8	3.96	28	2.19	16	3.12	10	3.78	7	4.40	47	1.64	24	2.57	14	3.40	9	4.09
	50	44	1.81	24	2.66	16	3.28	11	3.88	9	4.00	33	2.33	19	3.21	13	3.76	10	4.24	34	2.28	19	3.35	12	4.11	8	4.78	57	1.70	29	2.69	17	3.60	11	4.40
	60	52	1.85	28	2.78	18	3.50	13	4.14	10	4.13	39	2.39	23	3.32	16	3.96	11	4.35	40	2.35	21	3.60	14	4.36	10	5.08	67	1.75	34	2.78	20	3.84	13	4.62
	70	59	1.90	32	2.87	21	3.67	14	4.32	11	4.54	45	2.44	27	3.40	18	4.12	13	4.74	46	2.43	24	3.73	16	4.55	-	-2/	77	1.78	39	2.85	22	4.03	-	-2/
	80	67	1.91	36	2.94	23	3.75	16	4.53	13	4.84	51	2.48	30	3.46	20	4.25	15	4.91	51	2.49	27	3.83	18	4.71			87	1.80	44	2.90	25	4.11		
	90	75	1.93	40	3.00	26	3.87	18	4.62	14	5.00	57	2.51	34	3.51	23	4.36	16	5.05	57	2.54	30	3.98	20	4.34			97	1.82	49	2.94	28	4.17		
	100	83	1.95	44	3.05	28	3.98	21	4.70	16	5.12	63	2.53	37	3.55	25	4.44	18	5.16	63	2.56	32	4.10	-	-2/			107	1.84	54	2.98	31	4.22		
	120	100	1.95	52	3.12	33	4.12	24	4.92	18	5.11	75	2.57	45	3.61	30	4.58	21	5.35	73	2.65	38	4.20					127	1.86	62	3.12	36	4.41		
	140	116	1.97	60	3.18	38	4.20	27	5.08	-	-2/	87	2.60	52	3.66	34	4.69	25	5.49	84	2.71	44	4.31					147	1.88	71	3.20	42	4.46		
	160	132	1.98	68	3.23	43	4.29	31	5.21			99	2.62	59	3.69	39	4.77		2/	94	2.78	49	4.41					167	1.89	80	3.23	48	4.54		
	180	148	1.99	75	3.30	48	4.36	35	5.24			111	2.63	66	3.72	43	4.83			104	2.81	55	4.44					187	1.90	90	3.26	53	4.60		
	200	164	2.00	83	3.33	54	4.40	38	5.31			123	2.65	73	3.74	48	4.89			114	2.87	61	4.51					207	1.91	99	3.28	-	-2/		
	240	196	2.01	99	3.38	64	4.49	-	-			147	2.67	88	3.78	57	4.97			133	2.95	72	4.58					247	1.93	118	3.32		
	280	228	2.02	114	3.42	74	4.56					171	2.68	102	3.80	66	5.03			153	3.01	84	4.63					287	1.94	137	3.34		
	320	260	2.03	130	3.44	83	4.64					195	2.69	117	3.82	76	5.08			172	3.06	95	4.67					327	1.94	156	3.36		
	360	292	2.03	146	3.45	93	4.67					219	2.70	131	3.84	85	5.11			190	3.11	-	-					367	1.95	175	3.39		
	400	324	2.04	162	3.47	103	4.73					243	2.71	145	3.85	94	5.14			200	3.30							-	-3/	-	-3/		
	440	-	-	177	3.49	113	4.75					267	2.71	160	3.86	103	5.17			209	3.46												
	480			192	3.52	123	4.77					291	2.72	174	3.87	112	5.19			218	3.62												
	520			207	3.54	133	4.78					315	2.72	188	3.38	122	5.21			228	3.76												

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example

Slope = 8% d = 0.8'
Find b & v for Q = 470 cfs
30/40 = .75 this is the proportional part of increment between the respective discharges.
b = 112 - 103 = (9 x .75) + 103 = 110'
v = 5.19 - 5.17 = (2 x .75) + 5.17 = 5.19 fps

Find "b" & "v" for Q = 400 cfs, Slope = 7.6% d = 0.8'

Slope 7%	Slope 8%
b = 103	b = 94
v = 4.73	v = 5.14

For Slope 7.6% b = 103 - 9 = 9
b = 9 x .6 = 5.4, 103 - 5.4 = 97.6'
v = 5.14 - 4.73 = .31
v = .31 x 6 = .186, 4.73 + .19 = 4.92 fps

d = design flow depth
D = d + 0.5' freeboard
T = constructed top width
t = b + 8d
D = constructed depth
T = b + 8D
b = bottom width from table

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)
2/ Approaching Critical Discharge
3/ Max. Bottom Width (arbitrary) Approx. 300'

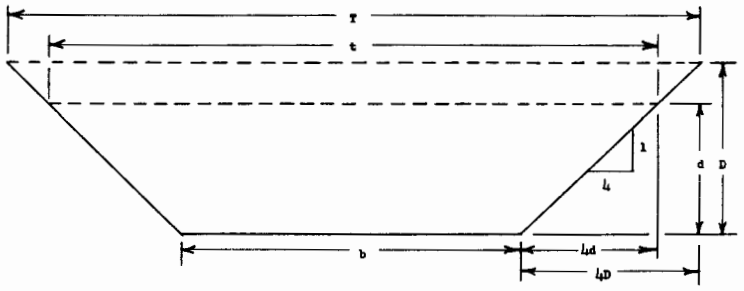


Figure 5.2 (cont'd)

TRAPEZOIDAL WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "C"

Drg. Area Acres	cfs dsch	Slope = 0.5%											
		d = 1.2		d = 1.4		d = 1.6		d = 1.8		d = 2.0		d = 2.2	
		b	v	b	v	b	v	b	v	b	v	b	v
	10	6	0.77	3	0.82	1	0.89						
	20	9	1.19	5	1.30	3	1.36						
	30	13	1.44	8	1.59	5	1.69	2	1.77				
	40	16	1.63	10	1.82	7	1.94	4	2.04	2	2.08		
	50	19	1.76	12	2.00	8	2.14	5	2.31	3	2.29		
	60	22	1.85	14	2.15	10	2.33	6	2.49	4	2.48	2	2.55
	70	26	1.93	16	2.28	11	2.46	8	2.65	5	2.65	3	2.72
	80	29	1.99	18	2.38	13	2.56	9	2.78	6	2.80	4	2.89
	90	32	2.04	21	2.45	15	2.67	10	2.87	7	2.94	5	3.01
	100	35	2.09	23	2.52	16	2.75	11	2.99	8	3.05	6	3.13
	120	42	2.16	27	2.62	19	2.91	14	3.12	10	3.26	8	3.35
	140	48	2.21	31	2.70	23	3.03	17	3.24	12	3.43	9	3.54
	160	54	2.25	36	2.77	26	3.12	19	3.35	15	3.54	11	3.67
	180	61	2.29	40	2.81	29	3.20	22	3.45	17	3.66	13	3.81
	200	67	2.31	44	2.86	32	3.26	24	3.52	19	3.75	15	3.90
	240	80	2.36	53	2.93	38	3.36	29	3.64	23	3.90	18	4.07
	280	93	2.39	61	2.99	45	3.42	34	3.75	27	4.02	21	4.23
	320	106	2.41	70	3.02	51	3.49	39	3.82	31	4.11	25	4.34
	360	119	2.43	79	3.05	57	3.53	44	3.89	35	4.19	28	4.43
	400	132	2.44	87	3.07	64	3.57	49	3.95	39	4.25	32	4.51
	440	144	2.46	96	3.10	70	3.61	54	3.99	43	4.30	35	4.58
	480	157	2.47	105	3.11	76	3.63	59	4.03	47	4.34	38	4.63
	520	171	2.47	113	3.13	83	3.66	64	4.06	51	4.38	42	4.66

Drg. Area Acres	cfs dsch	Slope = 1.0%											
		d = 0.8		d = 1.0		d = 1.2		d = 1.4		d = 1.6		d = 1.8	
		b	v	b	v	b	v	b	v	b	v	b	v
	10	9	0.99	4	1.22								
	20	16	1.28	9	1.69	4	1.83	2	1.97				
	30	23	1.45	11	1.96	6	2.25	3	2.44	1	2.50		
	40	29	1.56	15	2.04	8	2.54	5	2.77	2	2.84		
	50	35	1.64	18	2.29	10	2.76	6	3.05	4	3.13	1	3.23
	60	41	1.69	21	2.41	12	2.94	8	3.25	5	3.38	2	3.51
	70	47	1.74	24	2.52	14	3.09	9	3.42	6	3.58	3	3.74
	80	53	1.77	27	2.60	16	3.22	10	3.57	7	3.88	4	3.93
	90	59	1.80	30	2.67	18	3.32	12	3.67	8	3.91	5	4.13
	100	66	1.82	33	2.73	20	3.40	13	3.76	9	4.03	6	4.27
	120	78	1.85	38	2.84	24	3.53	16	3.91	11	4.26	8	4.50
	140	90	1.88	44	2.90	27	3.63	19	4.05	13	4.44	9	4.69
	160	102	1.90	50	2.96	31	3.72	22	4.14	15	4.59	11	4.88
	180	115	1.91	56	3.01	35	3.79	25	4.22	18	4.71	13	5.00
	200	127	1.92	62	3.05	39	3.85	28	4.28	20	4.81	15	5.09
	240	151	1.94	73	3.11	46	3.93	34	4.37	24	4.96	18	5.31
	280	175	1.96	85	3.16	54	4.00	39	4.45	28	5.10	21	5.48
	320	200	1.97	96	3.19	61	4.05	45	4.51	32	5.21	25	5.59
	360	225	1.98	108	3.21	69	4.09	51	4.55	36	5.28	28	5.70
	400	249	1.98	120	3.23	76	4.13	57	4.59	40	5.35	31	5.79
	440	274	1.98	131	3.25	84	4.15	63	4.61	44	5.41	35	5.85
	480	299	1.99	143	3.27	91	4.17	68	4.63	49	5.45	38	5.92
	520	321	1.99	155	3.28	99	4.19	74	4.66	53	5.49	41	5.97

Drg. Area Acres	cfs dsch	Slope = 2.0%									
		d = 0.9		d = 1.0		d = 1.1		d = 1.2		d = 1.3	
		b	v	b	v	b	v	b	v	b	v
	10	3	1.68	2	1.75						
	20	6	2.44	4	2.63	2	2.70	2	2.72		
	30	7	3.14	5	3.19	4	3.24	3	3.33	2	3.34
	40	10	3.19	7	3.57	6	3.63	4	3.79	3	3.85
	50	13	3.40	9	3.81	7	3.91	5	4.08	4	4.23
	60	15	3.58	11	4.00	9	4.16	7	4.37	5	4.52
	70	17	3.73	13	4.19	10	4.35	8	4.59	6	4.76
	80	20	3.84	15	4.27	12	4.57	9	4.78	7	4.96
	90	22	3.93	17	4.39	13	4.70	10	4.93	8	5.12
	100	24	3.98	18	4.46	15	4.81	12	5.07	9	5.26
	120	29	4.07	22	4.59	17	5.00	14	5.28	12	5.52
	140	34	4.14	26	4.69	20	5.15	17	5.44	14	5.71
	160	39	4.20	30	4.77	23	5.27	19	5.57	2/	
	180	44	4.24	33	4.83	26	5.37	22	5.67		
	200	48	4.28	37	4.88	29	5.44	24	5.76		
	240	58	4.33	44	5.02	35	5.58	29	5.93		
	280	68	4.37	51	5.12	40	5.67	34	6.07		
	320	77	4.40	58	5.19	46	5.75	38	6.17		
	360	87	4.42	64	5.26	2/		2/			
	400	96	4.44	71	5.31						
	440	106	4.46	78	5.35						
	480	116	4.47	85	5.38						
	520	125	4.48	92	5.41						

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 1.0% d = 1.4'
Find b & v for Q = 415 cfs
15/40 = .375 this is the proportional part of increment between the respective discharges.
b = 63 - 57 = (6 x .375) ≠ 57 = 59'
v = 4.61 - 4.59 = (.02 x .375) ≠ 4.59 = 4.59 fps.
Find "b" & "v" Q = 200 Slope = 1.4% d = 1.2'

Slope 2.0%	Slope 3.0%
b = 39'	b = 24'
v = 3.85	v = 5.76

For Slope 1.4% b = 39' - 24' = 15'
b = 15 x .4 = 6', b = 39 - 6 = 33'
v = 5.76 - 3.85 = 1.91
v = 1.91 x .4 = .76, v = 3.85 ≠ .76 = 4.61 fps

d = design flow depth
D = d ≠ 0.5' freeboard
T = constructed top width
t = b ≠ 8d
D = constructed depth
T = b ≠ 8D
b = bottom width from table

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)
2/ Approaching Critical Discharge
3/ Max. Bottom Width (arbitrary) Approx. 300'

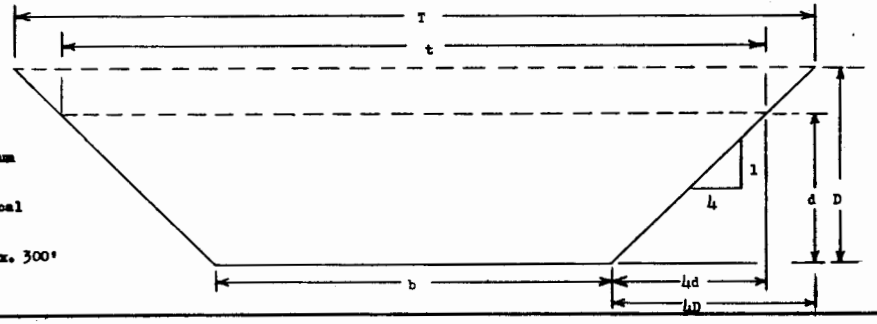


Figure 5.3

Sheet 2 of 2

TRAPEZOIDAL WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "C"

Drain Area Acres	Q cfs each	Slope = 3.0%												Slope = 4.0%										Slope = 5.0%						Slope = 6.0%						Slope = 7.0%			
		d = 0.6		d = 0.7		d = 0.8		d = 0.9		d = 1.0				d = 0.5		d = 0.6		d = 0.7		d = 0.8		d = 0.9		d = 0.5		d = 0.6		d = 0.7		d = 0.5		d = 0.6		d = 0.7		d = 0.5		d = 0.6	
		b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
	10	8	1.71	5	1.87	-								10	1.73	6	2.08	3	2.38	2	2.35	1	2.26	8	2.06	5	2.41	3	2.83	6	2.40	4	2.52	2	3.03	6	2.50	4	2.73
	20	14	2.03	8	2.64	5	2.97	4	3.12	-	-	-	-	17	2.07	11	2.58	6	3.24	4	3.52	3	3.58	14	2.48	8	3.14	5	3.66	12	2.89	7	3.40	4	4.20	11	3.20	7	3.74
	30	19	2.30	12	2.99	8	3.47	5	3.78	4	3.94	-	-	25	2.23	15	2.88	9	3.75	6	4.21	4	4.38	21	2.66	12	3.52	7	4.28	17	3.24	10	3.93		2/	15	3.63	9	4.38
	40	24	2.49	14	3.34	10	3.84	7	4.19	5	4.39			33	2.31	19	3.21	11	4.31	8	4.58	5	4.93	27	2.80	15	3.76	11	4.28	21	3.44	13	4.32			19	3.88		2/
	50	29	2.62	18	3.45	12	4.11	9	4.51	7	4.76			40	2.38	22	3.41	14	4.53	10	4.92		2/	32	2.91	19	3.94		2/	26	3.59		2/				2/		
	60	34	2.72	21	3.61	14	4.28	11	4.72	8	5.04			47	2.47	26	3.54	16	4.74		2/			38	2.99	22	4.06			30	3.71								
	70	39	2.79	24	3.73	17	4.44	12	4.92	9	5.26			54	2.50	30	3.64		2/					44	3.05	26	4.18			35	3.81								
	80	44	2.85	27	3.79	19	4.56	14	5.05	-	- 2/			61	2.53	34	3.71							50	3.08	29	4.27			39	3.87								
	90	49	2.90	30	3.87	21	4.66	-	- 2/					68	2.57	37	3.77							55	3.14	32	4.36			44	3.92								
	100	54	2.94	34	3.92	23	4.75							75	2.61	41	3.83							61	3.18	35	4.42			49	3.96								
	120	64	3.00	40	4.00	28	4.88							88	2.66	49	3.90							72	3.26		2/			58	4.03								
	140	74	3.04	46	4.06	32	4.98							102	2.70	57	3.96							82	3.32					67	4.08								
	160	84	3.08	53	4.11	36	5.06							115	2.72	64	4.01							93	3.37					76	4.12								
	180	94	3.11	59	4.14	-	- 2/							130	2.73	72	4.05							103	3.41					85	4.16								
	200	104	3.13	65	4.18									143	2.76	79	4.08							114	3.44					94	4.18								
	240	124	3.16	78	4.24									170	2.79	94	4.13							135	3.49														
	280	144	3.19	91	4.27									197	2.81	110	4.17							156	3.53														
	320	164	3.20	103	4.30									224	2.83		2/							178	3.56														
	360	184	3.22	116	4.32									251	2.84									199	3.58														
	400	204	3.23	129	4.34									279	2.85									220	3.60														
	440	224	3.24	141	4.36									306	2.85									241	3.61														
	480	243	3.25	154	4.37									333	2.86									262	3.63														
	520	263	3.25	167	4.38									360	2.76									273	3.64														

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example

Slope = 4% d = 0.6'
Find b & v for Q = 145 cfs
5/20 = .25 this is the proportional part of increase between the respective discharges.
b = 60 - 57 = (7 x .25) = 57 = 59'
v = 4.01 - 3.96 = (5 x .25) = 3.96 = 3.97 fps

Find "b" & "v" for Q = 100 cfs, Slope = 3.4%, d = 0.6'

Slope 3%	Slope 4%
b = 54	b = 41
v = 2.94	v = 3.83

For Slope 3.4%, b = 54 - 41 = 13
b = 13 x .4 = 5.2' b = 54 - 5.2 = 48.8'
v = 3.83 - 2.94 = .89
v = .89 x .4 = .36, b = 2.94 = .36 = 3.32 fps

d = design flow depth
D = d + 0.5' freeboard
T = constructed top width
t = b + 8d
D = constructed depth
T = b + 8D
b = bottom width from table

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)

2/ Approaching Critical Discharge

3/ Max. Bottom Width (arbitrary) Approx. 300'

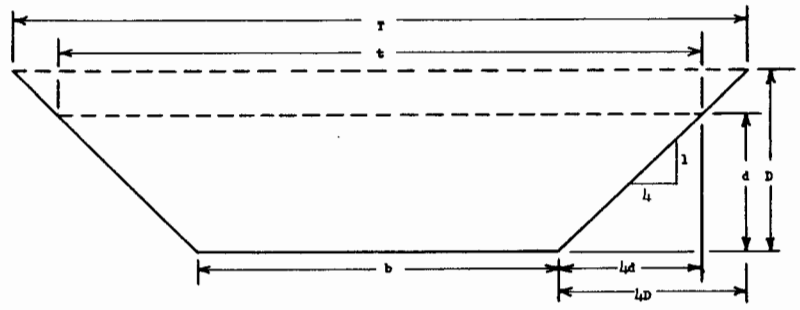


Figure 5.3 (cont'd)

TRAPEZOIDAL WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "D"

		Slope = 0.5%												Slope = 1.0%														Slope = 2.0%										Slope = 3.0%										Slope = 4.0%						Slope=5.0%				Slope=6%	
		d=0.8		d=1.0		d=1.2		d=1.4		d=1.6		d=1.8		d=0.7		d=0.8		d=0.9		d=1.0		d=1.1		d=1.2		d=0.5		d=0.6		d=0.7		d=0.8		d=0.9		d=0.5		d=0.6		d=0.7		d=0.8		d=0.9		d=0.5		d=0.6		d=0.7		d=0.5		d=0.6		d=0.5	
	cfs	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v	b	v
	10	8	1.15	4	1.88	2	1.26	-	-	-	-	-	-	6	1.56	4	1.74	3	1.76	1	1.92	-	-	-	-	9	1.30	6	2.11	3	2.38	2	2.40	1	2.42	6	2.44	4	2.56	2	2.36	1	2.90	-	-	5	3.06	3	3.08	2	3.10	4	3.13	3	3.39	4	3.41
	20	15	1.36	9	1.59	5	1.72	2	1.83	-	-	-	-	12	1.96	9	2.08	6	2.24	4	2.41	3	2.39	2	2.53	18	2.05	11	2.43	7	2.87	5	3.05	3	3.17	13	2.76	8	3.12	5	3.57	3	3.85	2	4.27	10	3.53	7	3.68	4	4.08	9	3.77				
	30	22	1.46	13	1.76	8	2.00	4	2.14	2	2.18	-	-	18	2.01	13	2.27	10	2.53	7	2.65	6	2.73	4	2.97	26	2.17	17	2.63	11	3.15	8	3.41	6	3.58	19	2.91	12	3.45	8	3.90	6	4.31	4	4.57	15	3.53	10	4.10		2/		2/		2/		2/
	40	30	1.54	17	1.99	11	2.16	7	2.32	4	2.43	1	2.71	24	2.15	18	2.40	13	2.66	10	2.86	8	2.98	6	3.12	34	2.23	22	2.77	14	3.32	11	3.62	8	3.93	25	3.01	16	3.66	11	4.14	8	4.55		2/	20	3.54	13	4.30						
	50	36	1.58	21	1.98	13	2.30	9	2.50	6	2.60	3	2.81	30	2.20	22	2.50	16	2.79	13	2.99	10	3.16	8	3.43	42	2.27	27	2.95	18	3.45	13	3.81	10	4.15	30	3.10	20	3.79	14	4.33		2/			25	3.75		2/						
	60	43	1.61	25	2.05	16	2.42	11	2.61	7	2.76	4	2.92	36	2.23	26	2.55	20	2.89	15	3.11	12	3.27	10	3.42	50	2.31	32	2.92	21	3.54	16	3.95	12	4.30	36	3.16	23	3.88	16	4.46			29	3.82								
	70	51	1.63	29	2.05	19	2.49	13	2.72	9	2.90	6	3.01	41	2.26	30	2.62	23	2.97	18	3.20	14	3.38	12	3.54	58	2.33	37	2.96	25	3.61	19	4.03	14	4.37	42	3.24	27	3.95	19	4.61			34	3.88								
	80	58	1.64	33	2.15	21	2.55	15	2.80	10	3.01	7	3.11	47	2.28	35	2.65	26	3.01	20	3.28	16	3.50	13	3.66	66	2.35	42	3.00	28	3.66	21	4.12	16	4.49	47	3.24	31	4.02		2/			39	3.95								
	90	65	1.66	37	2.18	24	2.60	17	2.88	12	3.07	8	3.21	53	2.29	39	2.68	29	3.06	25	3.35	19	3.56	15	3.75	74	2.37	47	3.02	32	3.71	24	4.18	18	4.55	53	3.27	35	4.05						2/								
	100	72	1.67	41	2.22	27	2.65	19	2.94	15	3.14	10	3.27	59	2.30	43	2.71	32	3.10	25	3.40	21	3.64	17	3.84	82	2.38	52	3.05	35	3.74	26	4.25	21	4.61	58	3.31	38	4.08														
	120	86	1.68	49	2.27	32	2.72	23	3.03	17	3.28	11	3.42	71	2.32	51	2.75	39	3.15	31	3.48	25	3.75	20	3.97	98	2.40	63	3.08	42	3.79	31	4.34	25	4.69	70	3.34	46	4.14														
	140	100	1.69	56	2.30	37	2.76	27	3.10	20	3.37	16	3.53	83	2.34	60	2.78	45	3.19	36	3.54	29	3.83	24	4.07	114	2.41	73	3.11	49	3.83	37	4.40	29	4.77	81	3.37	53	4.18														
	160	114	1.70	65	2.33	43	2.81	31	3.15	23	3.46	17	3.64	95	2.34	68	2.80	51	3.23	41	3.58	33	3.88	27	4.14	130	2.42	83	3.13	56	3.86	42	4.44	33	4.82	92	3.39	61	4.22														
	180	129	1.71	73	2.35	48	2.84	35	3.20	25	3.54	20	3.75	107	2.35	77	2.82	58	3.26	46	3.62	37	3.93	31	4.21	146	2.43	93	3.14	63	3.88	47	4.48	38	4.87	104	3.41	69	4.23														
	200	143	1.71	81	2.36	53	2.87	39	3.24	28	3.59	22	3.82	119	2.35	85	2.83	64	3.28	51	3.66	41	3.98	34	4.26	162	2.44	103	3.15	71	3.90	52	4.51	42	4.91	115	3.42	76	4.25														
	240	171	1.72	97	2.37	64	2.91	46	3.32	34	3.69	27	3.94	143	2.35	102	2.85	77	3.30	61	3.71	50	4.04	41	4.34	194	2.45	124	3.17	84	3.95	63	4.56	50	4.96	137	3.44	71	4.28														
	280	200	1.73	112	2.41	75	2.94	54	3.37	40	3.76	31	4.04	167	2.36	119	2.86	90	3.33	71	3.74	58	4.09	48	4.39	226	2.45	144	3.19	98	3.96	73	4.59	59	5.00	160	3.45	106	4.30														
	320	228	1.73	128	2.42	85	2.96	61	3.41	46	3.80	36	4.11	191	2.36	136	2.87	103	3.35	81	3.77	66	4.12	55	4.44	258	2.46	165	3.20	112	3.98	83	4.62	67	5.01	183	3.46	121	4.31														
	360	256	1.73	144	2.43	96	2.99	69	3.45	52	3.85	41	4.18	215	2.36	153	2.88	115	3.36	91	3.79	74	4.15	62	4.48	290	2.47	185	3.20	126	3.99	94	4.64	76	5.04	205	3.47	136	4.32														
	400	285	1.74	160	2.44	106	3.00	77	3.48	58	3.89	45	4.22	239	2.37	170	2.88	128	3.37	101	3.81	83	4.18	69	4.50	322	2.47	205	3.21	140	4.00	104	4.66	84	5.07	228	3.48	152	4.33														
	440	313	1.74	176	2.45	117	3.01	84	3.50	64	3.92	50	4.26	263	2.37	187	2.89	141	3.38	111	3.82	91	4.20	75	4.53	354	2.47	226	3.21	154	4.01	115	4.67	93	5.09	250	3.48	167	4.34														
	480	342	1.74	191	2.46	128	3.02	92	3.52	70	3.95	55	4.30	287	2.37	204	2.89	154	3.39	121	3.83	99	4.21	83	4.56	386	2.47	246	3.22	168	4.02	125	4.68	-	-	273	3.49	182	4.35														
	520	370	1.74	207	2.46	138	3.03	98	3.54	76	3.97	59	4.34	311	2.37	221	2.90	167	3.39	131	3.84	108	4.22	90	4.58	418	2.48	267	3.22	182	4.03	135	4.69	-	-	296	3.50	197	4.35														

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example

Slope = 2.0% d = 0.7
Find b & v for Q = 855 cfs
35/40 = .875 this is the proportional part of increment between the respective discharges.
b = 84 - 71 = (13 x .875) + 71 = 82'
v = 3.93 - 3.90 = (3 x .875) + 3.90 = 3.92 fps

Find 'b' & 'v' for Q = 180 cfs, Slope = 1.6 % d = 0.9'
Slope 1% Slope 2%
b = 58 b = 38
v = 3.26 v = 4.87
For Slope 1.6%, b = 58 - 38 = 20'
b = 20 x .6 = 12', b = 58 - 12 = 46'
v = 4.87 - 3.26 = 1.61
v = 1.61 x .6 = .97, v = 3.26 + .97 = 4.23 fps,

d = design flow depth
D = d + 0.5' freeboard
T = constructed top width
t = b + 8d
D = constructed depth
T = b + 8D
b = bottom width from table

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)

2/ Approaching Critical Discharge

3/ Max. Bottom Width (arbitrary) Approx. 300'

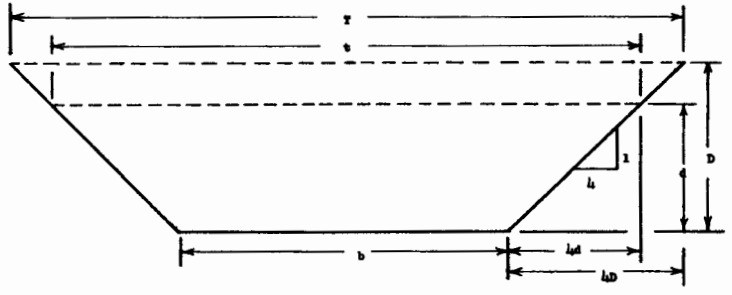


Figure 5.4

PARABOLIC WATERWAY DIMENSION CHART — Sheet 1 of 2

VEGETATIVE ESTARDANCE "A"

Drain Area Acres	cfs Disch	Slope = 0.5%								Slope = 1.0%							
		d=2.5'		d=3.0'		d=3.5'		d=4.0'		d=2.5'		d=3.0'		d=3.5'		d=4.0'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	14	4/4	10	.45	10	.45	9	.45	9	.65	7	.68	6	.74	5	.75
	20	27	4/4	18	.55	12	.73	10	.76	16	.75	10	.97	8	1.13	6	1.25
	30	41	.45	27	.55	14	.91	11	1.00	23	.78	12	1.27	9	1.43	7	1.66
	40	54	.45	36	.55	16	1.06	13	1.20	30	.81	13	1.52	10	1.68	8	1.95
	50	67	.45	45	.55	19	1.16	14	1.36	37	.82	15	1.71	11	1.99	9	2.21
	60	81	.45	54	.55	21	1.24	15	1.49	44	.83	16	1.88	12	2.24	9	2.40
	70	94	.45	63	.55	23	1.31	16	1.60	50	.84	17	2.01	12	2.44	10	2.58
	80	107	.45	72	.55	25	1.36	18	1.69	57	.84	19	2.13	13	2.60	11	2.73
	90	120	.45	81	.55	27	1.41	19	1.76	64	.85	20	2.21	14	2.74	12	2.88
	100	134	.45	90	.55	30	1.44	20	1.85	71	.85	22	2.27	15	2.84	13	3.00
	120	160	.45	108	.55	34	1.50	23	1.96	85	.86	25	2.36	17	3.03	14	3.22
	140	187	.45	126	.55	38	1.58	26	2.05	98	.86	29	2.42	19	3.16	16	3.39
	160	214	.45	144	.55	43	1.60	28	2.11	112	.86	33	2.45	21	3.27	17	3.54
	180	240	.45	162	.55	48	1.62	31	2.18	126	.86	36	2.49	23	3.33	19	3.69
	200	267	.45	180	.55	52	1.65	34	2.23	140	.86	40	2.49	25	3.39	20	3.81
	240	320	.45	216	.56	61	1.69	39	2.32	167	.86	48	2.49	30	3.43	23	3.93
	280	3/		252	.56	70	1.72	44	2.38	195	.86	56	2.50	35	3.44	26	4.01
	320			288	.56	79	1.74	50	2.42	222	.87	65	2.50	40	3.45	30	4.07
	360			324	.56	88	1.76	55	2.46	250	.87	76	2.50	45	3.46	33	4.11
	400			3/		96	1.78	60	2.49	277	.87	87	2.50	50	3.46	36	4.14
	440					105	1.79	65	2.52	305	.87	97	2.50	55	3.46	40	4.15
	480					114	1.80	70	2.55	3/		108	2.50	60	3.46	43	4.15
	520					123	1.81	76	2.57			118	2.50	65	3.46	47	4.15

Drain Area Acres	cfs Disch	Slope = 2.0%								Slope = 3.0%							
		d=2.0'		d=2.5'		d=3.0'		d=3.5'		d=1.5'		d=2.0'		d=2.5'		d=3.0'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	8	.99	6	1.04	5	.98	5	.90	10	.84	7	1.15	5	1.18	4	1.19
	20	12	1.25	7	1.62	6	1.64	5	1.63	24	.84	10	1.56	6	2.04	5	2.04
	30	16	1.37	9	1.98	7	2.11	6	2.22	36	.84	12	1.85	7	2.61	6	2.68
	40	21	1.44	11	2.24	8	2.50	6	2.68	48	.84	14	2.09	8	3.10	6	3.23
	50	25	1.48	12	2.45	9	2.78	7	3.11	60	.84	17	2.27	9	3.45	7	3.62
	60	30	1.51	14	2.59	10	3.00	8	3.43	72	.84	19	2.44	10	3.72	8	4.00
	70	35	1.52	16	2.70	11	3.24	8	3.71	83	.84	21	2.54	11	3.93	8	4.27
	80	39	1.53	17	2.79	12	3.41	9	3.99	95	.84	23	2.63	12	4.11	9	4.55
	90	44	1.55	19	2.88	13	3.57	9	4.17	107	.84	26	2.69	13	4.22	10	4.74
	100	48	1.55	20	2.94	14	3.70	10	4.29	119	.84	28	2.70	14	4.32	10	4.84
	120	58	1.55	24	3.04	15	3.97	11	4.64	142	.84	33	2.70	16	4.50	12	5.17
	140	68	1.55	27	3.11	17	4.17	13	4.80	166	.84	39	2.70	18	4.61	13	5.38
	160	77	1.55	30	3.18	19	4.30	14	4.99	189	.85	44	2.70	21	4.69	14	5.56
	180	87	1.55	34	3.23	20	4.46	15	5.11	213	.85	50	2.70	23	4.74	16	5.69
	200	97	1.55	37	3.27	22	4.50	17	5.20	236	.85	55	2.71	25	4.77	17	5.81
	240	116	1.55	44	3.31	25	4.60	19	5.39	283	.85	67	2.71	30	4.82	20	6.00
	280	136	1.55	51	3.31	30	4.65	22	5.46	330	.85	78	2.71	35	4.86	23	6.06
	320	155	1.55	58	3.31	34	4.69	25	5.54	3/		89	2.71	39	4.89	26	6.13
	360	174	1.55	65	3.31	38	4.71	28	5.58			100	2.71	44	4.91	29	6.16
	400	194	1.55	73	3.31	42	4.71	31	5.60			111	2.71	49	4.93	32	6.17
	440	213	1.55	80	3.31	47	4.72	34	5.60			122	2.71	53	4.94	36	6.18
	480	233	1.55	87	3.31	51	4.72	37	5.60			133	2.71	58	4.96	39	6.18
	520	252	1.55	94	3.31	55	4.72	40	5.60			144	2.71	63	4.97	42	6.18

Drain Area Acres	cfs Disch	Slope = 4.0%								Slope = 5.0%							
		d=1.5'		d=2.0'		d=2.5'		d=3.0'		d=1.0'		d=1.5'		d=2.0'		d=2.5'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	10	1.03	5	1.50	4	1.36	4	1.32	20	.70	9	1.18	5	1.53	4	1.63
	20	17	1.16	7	2.31	5	2.36	4	2.27	42	.70	15	1.38	6	2.46	5	2.50
	30	25	1.19	8	2.81	6	3.10	5	3.13	64	.71	20	1.52	7	3.11	6	3.28
	40	34	1.19	9	3.19	7	3.63	6	3.64	85	.71	25	1.59	8	3.57	6	3.94
	50	42	1.20	11	3.44	7	4.11	6	4.17	106	.71	31	1.60	10	3.91	7	4.45
	60	50	1.20	13	3.60	8	4.50	7	4.62	127	.71	37	1.62	11	4.17	7	4.87
	70	58	1.20	14	3.75	9	4.72	7	4.95	148	.71	43	1.64	12	4.34	8	5.19
	80	67	1.20	16	3.84	10	4.95	8	5.26	169	.71	49	1.64	13	4.48	9	5.49
	90	75	1.20	17	3.93	11	5.14	8	5.49	190	.71	54	1.66	15	4.60	9	5.81
	100	83	1.20	19	3.99	11	5.31	9	5.71	211	.71	60	1.66	16	4.69	10	5.95
	120	100	1.20	22	4.06	13	5.50	10	6.06	253	.71	72	1.66	19	4.79	12	6.21
	140	117	1.20	26	4.11	15	5.68	11	6.36	295	.71	84	1.66	22	4.87	13	6.35
	160	134	1.20	29	4.13	17	5.78	12	6.53	337	.72	96	1.66	24	4.93	15	6.49
	180	151	1.20	30	4.16	19	5.84	13	6.72	3/		108	1.66	27	4.97	16	6.59
	200	168	1.20	36	4.17	20	5.93		2/			120	1.66	30	4.99	18	6.67
	240	202	1.20	43	4.18	24	6.00					144	1.66	36	5.04	21	6.80
	280	236	1.20	50	4.20	28	6.02						1.66	42	5.05	25	6.83
	320	270	1.20	57	4.20	32	6.04						1.66	48	5.05	28	6.91
	360	304	1.20	64	4.20	36	6.04						1.67	54	5.05	31	6.98
	400	3/		71	4.21	40	6.04						1.67	60	5.05	35	6.96
	440			79	4.21	44	6.04						1.67	66	5.05		2/
	480			86	4.21	48	6.05						1.67	82	5.05		
	520			93	4.21	51	6.07						1.67	78	5.05		

Note: To interpolate on this chart use a straight line ratio between the respective discharges.

Example: Slope = 3.0%, d = 2.5'
Find "t" & "v" for Q = 145 cfs
5/20 = .25 this is the proportional part of increment between the respective discharges.
"t" = 21 - 18 = 3', 3 x .25 = .75
"t" = 18 + .75 = 19'
"v" = 4.69 - 4.61 = .08 fps, 3 x .08 = .024 fps
"v" = 4.61 + .024 = 4.63 fps
Find "t" & "v" for Q = 200 cfs, d = 2.0', Slope = 3.5%

Slope 3.0%	Slope 4.0%
t 55'	t 36'
v 2.71 fps	v 4.17 fps

For Slope = 3.5%, t = 55 - 36 = 19'
t = .5 x 19 = 9.5 + 36 = 46'
v = 4.17 - 2.71 = 1.46 fps
v = .5 x 1.46 = .73 + 2.71 = 3.44 fps

d = design flow depth
D = d + 0.5' freeboard
t = design top width from table
T = t + 4 = constructed top width
At D/4 depth the width is T/2
At D/2 depth the width is 0.75T
These are points to be checked during construction

1/ Approaching maximum velocity 7 fps (arbitrary)

2/ Approaching critical discharge

3/ Maximum top width (arbitrary)

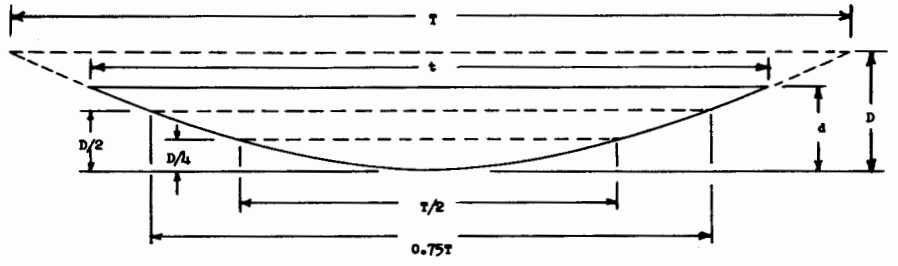


Figure 5.5

PARABOLIC WATERWAY DIMENSION CHART

Sheet 2 of 2

VEGETATIVE RETARDANCE "A"

Drain Area Acres	Q cfs	Slope = 6.0%										Slope = 7.0%									
		dm1.4'		dm1.6'		dm1.8'		dm2.0'		dm2.2'		dm1.2'		dm1.4'		dm1.6'		dm1.8'		dm2.0'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	9	1.26	6	1.63	5	1.85	4	1.83	4	1.36	13	.98	7	1.63	5	1.88	4	2.14	4	2.15
	20	15	1.45	9	2.13	6	2.90	5	2.86	5	2.87	25	1.00	11	2.04	7	2.68	5	3.27	5	3.34
	30	21	1.55	12	2.31	7	3.52	6	3.52	6	3.72	38	1.00	14	2.10	9	3.03	6	3.97	5	4.25
	40	27	1.57	16	2.39	9	3.92	7	4.05	6	4.40	50	1.00	18	2.15	12	3.19	8	4.39	6	4.80
	50	33	1.62	19	2.39	10	4.25	9	4.41	7	4.87	62	1.00	23	2.25	14	3.27	9	4.68	7	5.21
	60	39	1.63	21	2.40	11	4.42	10	4.74	8	5.28	74	1.00	28	2.25	17	3.27	10	4.90	8	5.49
	70	45	1.65	27	2.40	13	4.55	11	4.91	9	5.55	87	1.00	32	2.25	19	3.27	12	5.07	9	5.78
	80	51	1.67	31	2.40	15	4.59	12	5.08	10	5.74	99	1.00	37	2.25	22	3.27	13	5.21	10	5.95
	90	57	1.68	35	2.40	16	4.68	13	5.23	10	5.90	112	1.00	42	2.25	25	3.27	14	5.28	11	6.09
	100	64	1.68	39	2.40	18	4.69	14	5.36	11	6.06	124	1.00	47	2.25	28	3.27	16	5.38	12	6.15
	120	76	1.69	47	2.40	21	4.71	16	5.52	13	6.25	149	1.00	57	2.25	33	3.27	19	5.41	14	6.30
	140	89	1.69	55	2.40	25	4.72	19	5.64	15	6.36	174	1.00	67	2.25	39	3.27	22	5.43	17	6.37
	160	101	1.69	63	2.40	28	4.74	21	5.72	17	6.46	199	1.00	76	2.25	45	3.27	25	5.44	19	6.42
	180	114	1.70	71	2.40	32	4.76	23	5.82	19	6.55	224	1.00	86	2.25	52	3.27	28	5.45	21	6.44
	200	126	1.70	78	2.40	35	4.76	26	5.89	21	6.59	249	1.00	95	2.26	57	3.27	31	5.46	23	6.50
	240	151	1.70	94	2.40	42	4.78	30	4.96	25	6.65	299	1.00	114	2.27	69	3.27	37	5.48	28	6.50
	280	176	1.70	110	2.40	49	4.78	35	5.97	29	6.70	3/		132	2.27	80	3.28	43	5.48	32	6.57
	320	201	1.70	126	2.40	56	4.79	40	5.99	32	6.74			151	2.28	91	3.28	49	5.50	37	6.58
	360	226	1.70	141	2.40	63	4.80	45	5.99	36	6.76			169	2.28	102	3.29	55	5.50	41	6.61
	400	251	1.70	157	2.40	69	4.81	50	5.99	40	6.79			188	2.98	113	3.31	61	5.51	45	6.64
	440	276	1.70	173	2.40	76	4.81	56	5.99	44	6.80			206	2.29	125	3.31	67	5.51	50	6.66
	480	301	1.70	189	2.40	83	4.81	61	5.99	48	6.82			225	2.29	136	3.31	73	5.52	54	6.68
	520	3/		204	2.40	90	4.81	66	5.99	52	6.83			243	2.30	147	3.32	79	5.52	58	6.70

Drain Area Acres	Q cfs	Slope = 8.0%										Slope = 9.0%									
		dm1.0'		dm1.2'		dm1.4'		dm1.6'		dm1.8'		dm1.0'		dm1.2'		dm1.4'		dm1.6'		dm1.8'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	16	.92	9	1.47	4	2.49	3	3.41	2	3.97	14	1.01	7	1.69	4	2.90	2	4.46	1	5.95
	20	32	.93	17	1.49	9	2.49	5	3.61	3	4.90	29	1.01	15	1.69	7	3.15	4	4.58	3	6.41
	30	48	.94	25	1.50	12	2.61	8	3.70	4	5.18	44	1.01	22	1.70	10	3.18	6	4.59	4	6.58
	40	64	.94	33	1.50	16	2.65	10	3.79	6	5.46	59	1.01	29	1.71	13	3.23	8	4.59	5	6.67
	50	80	.94	41	1.51	20	2.70	12	3.83	7	5.63	74	1.01	37	1.71	17	3.25	10	4.59	6	6.72
	60	96	.94	50	1.51	24	2.71	15	3.86	9	5.75	89	1.01	44	1.71	20	3.26	12	4.59	7	6.75
	70	112	.94	58	1.51	28	2.73	17	3.87	10	5.83	104	1.01	51	1.72	23	3.28	14	4.59	9	6.78
	80	128	.94	66	1.51	31	2.75	19	3.87	11	5.90	119	1.01	58	1.72	26	3.30	16	4.59	10	6.80
	90	144	.94	75	1.51	35	2.75	22	3.88	13	5.95	134	1.01	66	1.72	29	3.30	18	4.59	11	6.82
	100	176	.94	83	1.51	39	2.76	24	3.89	14	5.95	149	1.01	73	1.72	33	3.30	20	4.59	12	6.83
	120	208	.94	99	1.51	46	2.78	29	3.90	17	6.02	179	1.01	88	1.72	39	3.32	25	4.59	15	6.85
	140	240	.94	116	1.51	54	2.78	34	3.91	19	6.08	209	1.01	102	1.72	45	3.32	29	4.59	17	6.86
	160	272	.94	132	1.51	62	2.79	38	3.92	22	6.12	239	1.01	117	1.72	52	3.33	33	4.59	19	6.87
	180	304	.94	149	1.51	69	2.80	43	3.92	25	6.12	269	1.01	131	1.72	58	3.33	37	4.59	22	6.88
	200	3/		165	1.51	77	2.80	48	3.93	27	6.15	299	1.01	146	1.72	64	3.33	41	4.59	24	6.89
	240			198	1.51	92	2.81	57	3.93	32	6.19	3/		175	1.72	77	3.33	49	4.59	29	6.90
	280			231	1.51	107	2.81	67	3.94	38	6.19			204	1.72	90	3.34	57	4.59	34	6.90
	320			264	1.51	122	2.81	76	3.94	43	6.22			233	1.72	103	3.34	65	4.59	39	6.91
	360			297	1.51	137	2.81	86	3.94	48	6.23			262	1.72	116	3.34	73	4.59	43	6.91
	400					152	2.81	95	3.94	54	6.23			291	1.72	128	3.35	82	4.59	48	6.91
	440					168	2.81	105	3.94	59	6.25			3/		141	3.35	90	4.59	53	6.92
	480					183	2.82	114	3.94	64	6.26					154	3.35	98	4.59	58	6.92
	520					198	2.82	124	3.94	69	6.26					167	3.35	106	4.59		1/

Drain Area Acres	Q cfs	Slope = 10%							
		dm1.0'		dm1.2'		dm1.4'		dm1.6'	
		t	v	t	v	t	v	t	v
	10	14	1.08	8	1.56	3	3.15	2	4.69
	20	28	1.08	16	1.56	6	3.51	4	5.26
	30	42	1.08	24	1.58	9	3.68	5	5.26
	40	55	1.08	32	1.58	12	3.70	7	5.26
	50	69	1.08	39	1.59	14	3.76	9	5.26
	60	83	1.08	47	1.60	17	3.79	11	5.26
	70	97	1.08	55	1.60	20	3.81	12	5.26
	80	111	1.08	63	1.60	23	3.81	14	5.26
	90	125	1.08	70	1.60	25	3.82	16	5.28
	100	139	1.08	78	1.60	28	3.83	18	5.28
	120	167	1.08	94	1.60	33	3.87	21	5.29
	140	195	1.08	109	1.60	39	3.87	25	5.29
	160	223	1.08	125	1.60	44	3.87	28	5.29
	180	251	1.08	141	1.60	50	3.88	32	5.29
	200	279	1.08	156	1.60	55	3.89	36	5.29
	240	3/		187	1.60	66	3.89	43	5.29
	280			219	1.60	77	3.90	50	5.29
	320			250	1.60	88	3.90	57	5.29
	360			281	1.60	99	3.91	64	5.29
	400			312	1.60	110	3.92	71	5.29
	440			3/		120	3.92	78	5.29
	480					131	3.93	85	5.29
	520					142	3.96	92	5.30

Note: To interpolate on this chart use a straight line ratio between the respective discharges
Example: Slope = 8.0%, d = 1.6'
Find "t" & "v" for Q = 145cfs
5/20 = .25 this is the proportional part of increment between the respective discharges.
"t" = 62 - 54 = 8 8 x .25 = 2'
"t" = 54 + 2 = 56'
"v" = 2.79 - 2.78 = .01, .01 x .25 = .0025 fps
v = 2.78 + .0025 = 2.78 fps
Find "t" & "v" for Q = 200cfs, d = 1.8', Slope = 8.6%
Slope 8.0% "t" = 27' "v" = 6.15 fps
Slope 9.0% "t" = 24' "v" = 6.89 fps
For Slope 8.6%, "t" = 27 - 24 = 3
= .6 x 3 = 1.8'
"t" = 27 - 1.8 = 25'
v = 6.89 - 6.15 = 0.74 fps
= .6 x .74 = .46 fps
v = 6.15 + .46 = 6.61 fps

d = design flow depth
D = d + 0.5' freeboard
t = design top width from table
T = t + 4 = constructed top width
At D/4 depth, the width is T/2
At D/2 depth, the width is 0.75T
These are the points to be checked during construction

1/ Approaching Maximum Velocity 7fps (arbitrary)

2/ Approaching Critical Discharge

3/ Maximum Top Width (arbitrary)

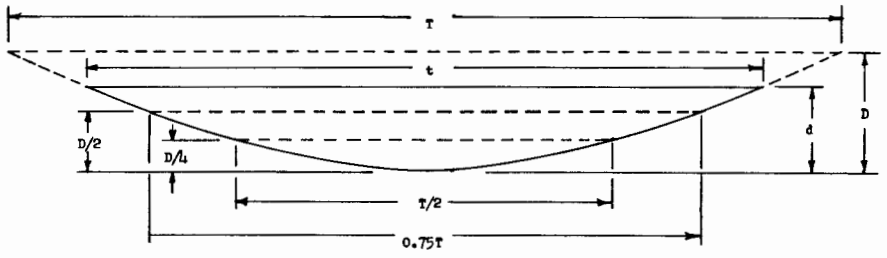


Figure 5.5 (cont'd)

PARABOLIC WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "B"

Q cfs	Slope = 0.5%								Slope = 1.0%								Slope = 2.0%							
	d=2.0'		d=2.5'		d=3.0'		d=3.5'		d=1.5'		d=2.0'		d=2.5'		d=3.0'		d=1.5'		d=2.0'		d=2.5'		d=3.0'	
	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
10	11	.66	7	.92	5	.94	5	.95	12	.86	6	1.29	5	1.30	3	1.61	6	1.64	5	1.67	4	1.62	2	2.50
20	18	.85	9	1.30	7	1.47	6	1.61	22	.90	9	1.73	6	1.97	4	2.43	9	2.20	6	2.64	4	2.72	3	3.84
30	24	.93	12	1.51	9	1.76	7	1.90	33	.90	12	1.94	8	2.40	5	2.94	13	2.24	7	3.19	5	3.46	3	4.54
40	31	.97	14	1.69	10	1.98	8	2.20	44	.90	15	2.06	9	2.70	6	3.27	17	2.33	9	3.49	6	4.00	4	5.00
50	38	1.00	17	1.73	12	2.14	9	2.42	55	.90	18	2.15	10	2.89	7	3.52	21	2.37	10	3.75	6	4.41	5	5.31
60	45	1.00	20	1.79	13	2.26	10	2.60	66	.90	21	2.19	12	3.03	8	3.70	25	2.39	12	3.92	8	4.74	5	5.66
70	52	1.00	23	1.82	15	2.33	11	2.75	78	.90	24	2.23	13	3.16	9	3.84	29	2.39	13	4.04	8	5.00	6	5.73
80	60	1.00	26	1.85	17	2.40	12	2.87	89	.90	28	2.25	15	3.25	10	3.96	34	2.39	15	4.14	9	5.22	7	5.79
90	67	1.00	29	1.86	18	2.47	13	2.97	100	.90	30	2.27	16	3.30	11	4.05	38	2.39	16	4.22	10	5.35	8	5.92
100	74	1.00	32	1.88	20	2.53	14	3.06	111	.90	33	2.29	18	3.36	12	4.13	42	2.40	18	4.29	11	5.50	8	6.02
120	90	1.00	38	1.91	23	2.59	16	3.17	134	.90	39	2.30	21	3.43	14	4.28	50	2.40	21	4.39	13	5.67	10	6.18
140	105	1.00	44	1.91	26	2.66	18	3.26	156	.90	46	2.30	24	3.47	16	4.37	58	2.41	24	4.47	14	5.83	11	6.36
160	121	1.00	50	1.91	29	2.74	21	3.34	178	.90	52	2.30	27	3.51	18	4.46	66	2.41	27	4.52	16	5.93	12	6.55
180	136	1.00	57	1.91	33	2.74	23	3.40	201	.90	59	2.31	31	3.53	20	4.52	75	2.41	30	4.55	18	6.04	14	6.66
200	152	1.00	63	1.92	36	2.76	25	3.44	223	.90	65	2.31	34	3.55	22	4.58	83	2.41	33	4.58	20	6.09	15	6.80
240	183	1.00	74	1.95	43	2.82	29	3.50	268	.90	78	2.31	40	3.59	26	4.65	100	2.41	39	4.61	23	6.18		1/
280	214	1.00	85	1.99	49	2.86	34	3.54	312	.90	91	2.31	47	3.60	30	4.69	116	2.41	46	4.61	27	6.22		
320	246	1.00	95	2.02	56	2.87	39	3.56	3/		104	2.31	53	3.60	34	4.74	133	2.41	52	4.61	31	6.25		
360	277	1.00	105	2.05	62	2.89	43	3.59			117	2.31	60	3.60	38	4.77	149	2.41	59	4.61	35	6.25		
400	308	1.00	115	2.08	69	2.89	48	3.61			130	2.31	67	3.60	42	4.80	166	2.41	65	4.61	39	6.25		
440	3/		125	2.11	76	2.89	52	3.61			143	2.31	73	3.60	46	4.82	183	2.41	72	4.61	43	6.25		
480			135	2.14	83	2.90	57	3.61			156	2.31	80	3.60	50	4.84	199	2.41	79	4.61	47	6.25		
520			145	2.15	90	2.90	62	3.62			169	2.31	87	3.60	53	4.86	216	2.41	86	4.61	51	6.25		

Q cfs	Slope = 3.0%								Slope = 4.0%								Slope = 5.0%							
	d=1.0'		d=1.5'		d=2.0'		d=2.5'		d=0.8'		d=1.2'		d=1.4'		d=1.6'		d=0.8'		d=1.2'		d=1.4'		d=1.6'	
	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
10	18	.86	5	2.00	3	2.27	3	2.07	27	.69	6	2.08	4	2.50	3	2.76	21	.89	5	2.50	4	2.82	3	2.84
20	35	.86	7	2.82	4	3.49	4	3.34	54	.69	10	2.50	6	3.46	5	3.83	42	.90	8	3.12	6	3.76	5	4.08
30	53	.86	9	3.23	5	4.17	4	4.29	81	.69	14	2.68	8	3.83	7	4.33	62	.91	11	3.34	8	4.23	6	4.77
40	70	.86	12	3.45	7	4.55	5	4.81	108	.69	18	2.72	11	4.05	8	4.69	83	.91	15	3.40	10	4.46	7	5.21
50	88	.86	14	3.62	8	4.94	6	5.27	135	.69	22	2.82	13	4.22	10	4.89	103	.91	18	3.47	12	4.62	8	5.39
60	105	.86	16	3.70	9	5.18	6	5.72	162	.69	27	2.83	15	4.26	11	4.97	124	.91	22	3.48	14	4.73	10	5.57
70	123	.86	19	3.78	10	5.36	7	6.00	189	.69	31	2.83	17	4.33	13	5.13	144	.91	25	3.50	16	4.79	12	5.57
80	140	.86	21	3.83	11	5.51	8	6.24	216	.69	35	2.84	20	4.33	15	5.14	165	.91	29	3.50	18	4.82	13	5.68
90	158	.86	23	3.84	12	5.68	8	6.43	243	.69	40	2.84	22	4.33	16	5.14	185	.91	32	3.51	20	4.85	15	5.70
100	175	.86	26	3.84	13	5.67	9	6.60	270	.69	44	2.85	25	4.33	18	5.15	206	.91	36	3.51	22	4.87	16	5.72
120	210	.86	31	3.84	15	5.85	11	6.86	324	.69	53	2.85	30	4.33	22	5.15	247	.91	43	3.51	27	4.87	19	5.74
140	245	.86	36	3.84	18	5.94		1/	3/		62	2.85	35	4.34	26	5.15	288	.91	50	3.51	31	4.89	23	5.74
160	280	.86	42	3.84	20	6.00					70	2.85	40	4.35	29	5.15	329	.91	57	3.51	35	4.90	26	5.74
180	315	.86	47	3.84	22	6.06					80	2.85	44	4.35	33	5.15	3/		64	3.51	39	4.91	29	5.74
200	3/		52	3.84	25	6.08					88	2.85	49	4.36	37	5.15			71	3.52	44	4.92	33	5.75
240			62	3.84	30	6.10					105	2.86	51	4.36	44	5.15			85	3.52	52	4.93	39	5.75
280			73	3.84	34	6.11					121	2.89	69	4.36	51	5.15			99	3.53	61	4.94	46	5.76
320			83	3.84	39	6.13					138	2.90	79	4.36	58	5.15			113	3.53	69	4.94	52	5.76
360			94	3.84	44	6.14					154	2.91	88	4.36	66	5.15			127	3.54	78	4.95	59	5.76
400			104	3.84	49	6.14					171	2.92	98	4.36	73	5.15			141	3.54	87	4.95	65	5.76
440			115	3.84	54	6.14					188	2.93	109	4.36	80	5.15			155	3.54	95	4.95	72	5.77
480			125	3.84	59	6.14					204	2.93	119	4.36	88	5.15			169	3.55	104	4.96	78	5.77
520			136	3.84	64	6.14					221	2.94	129	4.36	95	5.15			183	3.55	112	4.96	85	5.77

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 5.0% d = 1.6'
Find "t" & "v" for Q = 370 cfs
10/40 = .25 this is the proportional part of increment between the respective discharges.
t = 65 - 59 = (6 x .25) + 59 = 61
v = 5.76 - 5.76 = (0 x .25) + 5.76 = fps

Find "t" & "v" for Q = 200 cfs
Slope = 2.5%, d = 2.0'

Slope 3%		Slope 2%	
t	25	t	33
v	6.08	v	4.58

For Slope 2.5%, t = 33 - 25 =
8 x .5 = 4 + 25 = 29'
v = 6.08 - 4.58 = 1.50 x .5 = .75 + 4.58 = 5.33 fps

d = design flow depth
D = d + 0.5' freeboard
T = t + 4 = constructed top width
t = design top width from table
At D/4 depth, the width is T/2
At D/2 depth, the width is 0.75T
These are points to be checked during construction.

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)

2/ Approaching Critical Discharge

3/ Maximum Top Width (Arbitrary)

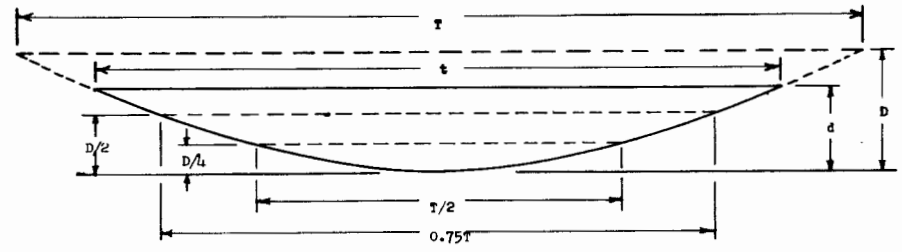


Figure 5.6

PARABOLIC VEGETATED CHANNEL — Sheet 2 of 2

VEGETATIVE RETARDANCE "B"

Drain Area Acres	Q cfs	Slope = 6.0%										Slope = 7.0%									
		d=0.8'		d=1.0'		d=1.2'		d=1.4'		d=1.6'		d=0.8'		d=0.9'		d=1.0'		d=1.1'		d=1.2'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	17	1.13	7	1.50	4	3.57	3	3.57	3	3.76	13	1.41	8	2.15	5	3.00	4	3.59	3	4.16
	20	31	1.19	12	2.48	6	3.96	5	4.21	4	5.08	26	1.47	15	2.17	10	3.00	7	3.84	6	4.54
	30	47	1.19	18	2.57	9	4.12	7	4.66	5	5.52	38	1.50	23	2.17	15	3.05	11	3.90	8	4.74
	40	63	1.19	23	2.61	12	4.16	9	5.00	6	5.96	50	1.50	31	2.19	20	3.05	14	3.97	10	4.80
	50	79	1.19	29	2.63	14	4.22	11	5.10	8	6.17	63	1.50	38	2.19	24	3.07	17	3.97	13	4.88
	60	94	1.19	34	2.65	18	4.26	12	5.25	9	6.26	75	1.50	46	2.19	29	3.08	21	3.99	15	4.91
	70	110	1.20	40	2.66	21	4.29	14	5.36	10	6.41	87	1.50	53	2.19	34	3.09	24	4.02	18	4.92
	80	125	1.20	45	2.66	23	4.30	16	5.43	12	6.42	100	1.50	61	2.19	39	3.09	27	4.03	20	4.93
	90	141	1.20	51	2.67	26	4.31	18	5.48	13	6.50	113	1.50	68	2.19	44	3.09	30	4.05	23	4.95
	100	156	1.20	56	2.68	29	4.32	19	5.53	14	6.56	126	1.50	76	2.19	49	3.09	34	4.05	25	4.96
	120	187	1.20	67	2.68	35	4.34	23	5.57	17	6.62	151	1.50	91	2.19	58	3.09	40	4.06	30	4.98
	140	218	1.21	78	2.68	40	4.34	27	5.64	20	6.70	177	1.50	106	2.19	68	3.09	47	4.08	35	5.00
	160	249	1.21	89	2.69	46	4.34	30	5.70		2/	202	1.50	122	2.19	78	3.10	54	4.08	40	5.01
	180	280	1.21	100	2.69	52	4.34	34	5.72			228	1.50	137	2.19	87	3.10	60	4.09	45	5.02
	200	311	1.21	111	2.70	57	4.35	37	5.75			253	1.50	152	2.19	97	3.10	67	4.09	50	5.02
	240	3/		133	2.70	69	4.36		2/			304	1.50	183	2.19	116	3.11	80	4.09	60	5.04
	280			155	2.70	80	4.36					3/		213	2.19	135	3.12	93	4.09	69	5.04
	320			177	2.71	92	4.36							244	2.19	156	3.12	107	4.10	79	5.04
	360			199	2.71	103	4.36							274	2.19	173	3.12	120	4.10	89	5.05
	400			221	2.71	115	4.36							305	2.19	192	3.13	133	4.10	99	5.05
	440			243	2.71	126	4.36							3/		211	3.13	146	4.10	109	5.06
	480			265	2.71	138	4.36									230	3.13	160	4.10	118	5.06
	520			287	2.71	149	4.36									249	3.13	173	4.10	128	5.07

Drain Area Acres	Q cfs	Slope = 8.0%										Slope = 9.0%									
		d=0.8'		d=0.9'		d=1.0'		d=1.1'		d=1.2'		d=0.7'		d=0.8'		d=0.9'		d=1.0'		d=1.1'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	9	2.08	6	2.83	4	3.41	3	4.20	2	5.55	18	1.21	10	1.98	6	2.82	4	3.66	3	4.20
	20	18	2.11	12	2.83	8	3.64	6	4.54	5	5.55	35	1.23	19	2.03	11	2.96	7	4.12	6	4.70
	30	26	2.14	18	2.83	12	3.72	9	4.68	7	5.55	52	1.24	27	2.06	17	3.03	11	4.21	8	4.97
	40	35	2.14	24	2.83	16	3.75	12	4.70	9	5.55	69	1.24	37	2.08	22	3.06	14	4.29	11	5.08
	50	44	2.14	30	2.83	20	3.80	15	4.70	11	5.55	86	1.24	45	2.08	27	3.06	17	4.34	13	5.15
	60	52	2.15	35	2.83	24	3.81	17	4.74	14	5.55	104	1.24	54	2.09	33	3.08	21	4.35	16	5.20
	70	61	2.15	41	2.84	28	3.82	20	4.75	16	5.57	121	1.24	63	2.09	38	3.09	24	4.36	18	5.24
	80	70	2.15	47	2.84	31	3.84	23	4.76	18	5.58	138	1.24	72	2.09	43	3.09	27	4.38	21	5.26
	90	79	2.15	53	2.84	35	3.84	26	4.77	20	5.59	155	1.24	81	2.09	49	3.09	31	4.39	23	5.28
	100	87	2.15	59	2.84	39	3.84	29	4.77	22	5.64	173	1.24	90	2.09	54	3.10	34	4.42	26	5.30
	120	104	2.17	70	2.84	47	3.85	34	4.80	27	5.60	207	1.24	108	2.09	65	3.10	41	4.43	31	5.33
	140	242	1.24	126	2.09	75	3.10	47	4.43	36	5.36	216	1.40	109	2.42	65	3.59	34	4.74		
	160	276	1.24	144	2.09	86	3.10	54	4.44	41	5.38	247	1.40	124	2.42	74	3.59	51	4.75		
	180	311	1.24	162	2.09	97	3.11	61	4.45	46	5.39	278	1.40	140	2.42	84	3.59	57	4.76		
	200	3/		180	2.09	107	3.11	67	4.46	51	5.41	309	1.40	155	2.42	93	3.60	63	4.76		
	240			216	2.09	128	3.12	81	4.47	61	5.42	3/		186	2.42	111	3.61	76	4.76		
	280			252	2.09	150	3.12	94	4.47	70	5.43			217	2.42	129	3.62	88	4.76		
	320			288	2.09	171	3.12	107	4.48	80	5.43			248	2.42	147	3.62		2/		
	360			324	2.09	192	3.13	121	4.48		2/			279	2.42	165	3.63				
	400			3/		213	3.13	134	4.49					310	2.42	184	3.63				
	440					234	3.13	147	4.49					3/		202	3.63				
	480					256	3.13	161	4.49							220	3.64				
	520					277	3.13	174	4.49							238	3.64				

Drain Area Acres	Q cfs	Slope = 10.0%							
		d=0.7'		d=0.8'		d=0.9'		d=1.0'	
		t	v	t	v	t	v	t	v
	10	16	1.36	8	2.35	5	3.27	4	4.06
	20	31	1.37	15	2.40	10	3.42	7	4.44
	30	46	1.39	24	2.40	14	3.50	10	4.50
	40	68	1.39	31	2.40	19	3.51	13	4.59
	50	77	1.40	39	2.41	24	3.53	16	4.66
	60	92	1.40	47	2.41	28	3.54	19	4.67
	70	108	1.40	55	2.41	33	3.56	23	4.69
	80	123	1.40	62	2.41	37	3.57	26	4.71
	90	139	1.40	70	2.41	42	3.57	29	4.72
	100	154	1.40	78	2.41	47	3.58	32	4.73
	120	185	1.40	93	2.42	56	3.59	38	4.74
	140	216	1.40	109	2.42	65	3.59	34	4.74
	160	247	1.40	124	2.42	74	3.59	51	4.75
	180	278	1.40	140	2.42	84	3.59	57	4.76
	200	309	1.40	155	2.42	93	3.60	63	4.76
	240	3/		186	2.42	111	3.61	76	4.76
	280			217	2.42	129	3.62	88	4.76
	320			248	2.42	147	3.62		2/
	360			279	2.42	165	3.63		
	400			310	2.42	184	3.63		
	440			3/		202	3.63		
	480					220	3.64		
	520					238	3.64		

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 8.0%, d = 1.0'
Find "t" & "v" for Q = 330 cfs
10/40 = .25 this is the proportional part of increment between the respective discharges.
"t" = 139 - 124 = 15, .25 x 15 = 3.75'
t = 124 + 3.75 = 128'
v = 3.89 - 3.89 = 0, v = 3.89 + 0 = 3.89fps
Find "t" & "v" for Q = 320 cfs, d = 1.0, Slope = 7.5%

Slope 8.0%	Slope 7.0%
t 124'	t 156'
v 3.89 fps	v 3.12 fps

For Slope = 7.5%, t = 156 - 124 = 32'
t = .50 x 32' = 16 + 124 = 140'
v = 3.89 - 3.12 = 0.75
v = 0.75 x .5 = 0.375 + 3.12 = 3.50 fps

d = design flow depth
D = dt + 0.5' freeboard
t = design top width from table
T = t + 4 = constructed top width
At D/4 depth the width is T/2
At D/2 depth the width is 0.75T
These are points to be checked during construction.

1/ Approaching maximum velocity 7fps (arbitrary)

2/ Approaching critical discharge

3/ Maximum top width (arbitrary)

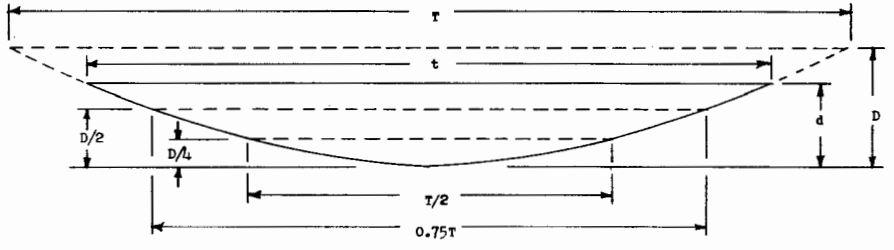


Figure 5.6 (cont'd)

PARABOLIC WATERWAY DIMENSION CHART — Sheet 1 of 2

VEGETATIVE RETARDANCE "C"

Drain Area Acres	Q cfs Dsch	Slope = 0.5%													
		d=1.0'		d=1.5'		d=2.0'		d=2.5'		d=3.0'		d=3.5'		d=4.0'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	30	.50	8	1.31	5	1.53	4	1.54	4	1.38	3	1.43	3	1.33
	20	60	.50	13	1.55	7	2.18	5	2.31	5	2.22	4	2.14	4	2.15
	30	90	.50	18	1.67	9	2.50	6	2.86	5	2.86	5	2.80	4	2.75
	40	120	.50	24	1.69	11	2.71	8	3.16	6	3.28	5	3.24	5	3.17
	50	150	.50	30	1.69	13	2.87	9	3.41	7	3.57	6	3.57	5	3.61
	60	180	.50	35	1.70	16	2.91	10	3.53	8	3.85	7	3.90	6	3.91
	70	210	.50	41	1.70	18	3.00	12	3.66	9	4.00	7	4.06	6	4.17
	80	240	.50	47	1.70	20	3.05	13	3.77	10	4.12	8	4.24	7	4.35
	90	270	.50	53	1.71	22	3.07	14	3.83	11	4.24	9	4.41	8	4.50
	100	300	.50	59	1.71	24	3.10	16	3.87	12	4.35	10	4.52	8	4.69
	120	--	3/	71	1.71	29	3.11	18	3.95	13	4.53	11	4.72	9	5.00
	140			72	1.71	34	3.13	21	3.99	15	4.61	12	4.92	10	5.20
	160			94	1.71	39	3.14	24	4.04	17	4.76	14	5.08	11	5.36
	180			105	1.71	43	3.14	27	4.05	19	4.76	15	5.22	12	5.51
	200			117	1.71	48	3.15	30	4.06	21	4.78	16	5.30	13	5.63
	240			141	1.71	57	3.15	35	4.09	25	4.88	19	5.42	16	5.77
	280			164	1.71	67	3.15	41	4.11	28	4.92	22	5.54	18	5.90
	320			188	1.71	76	3.15	47	4.13	32	4.97	25	5.58	20	6.00
	360			211	1.71	86	3.15	52	4.14	36	4.98	28	5.62	22	6.09
	400			235	1.71	95	3.16	58	4.15	40	4.98	30	5.65	24	6.15
	440			258	1.71	105	3.16	64	4.16	44	4.98	33	5.65	27	6.21
	480			282	1.71	114	3.16	69	4.17	48	4.98	36	5.65	29	6.25
	520			305	1.71	124	3.16	75	4.18	52	4.98	39	5.66	31	6.30

Drain Area Acres	Q cfs Dsch	Slope = 1.0%									
		d=1.0'		d=1.5'		d=2.0'		d=2.5'		d=3.0'	
		t	v	t	v	t	v	t	v	t	v
	10	13	1.13	4	2.39	3	2.27	3	2.18	3	1.85
	20	26	1.14	7	2.90	5	3.23	4	3.21	3	3.03
	30	39	1.16	9	3.28	6	3.75	5	3.92	4	3.98
	40	52	1.16	12	3.28	7	4.08	5	4.45	5	4.44
	50	65	1.16	15	3.33	9	4.29	6	4.80	5	4.90
	60	78	1.16	18	3.37	10	4.46	7	5.00	6	5.26
	70	91	1.16	21	3.37	12	4.57	8	5.25	6	5.56
	80	104	1.16	24	3.39	13	4.69	9	5.40	7	5.79
	90	117	1.16	27	3.40	14	4.74	10	5.50	8	6.00
	100	130	1.16	29	3.40	16	4.80	11	5.61	8	6.17
	120	156	1.16	35	3.40	18	4.90	13	5.77	9	6.45
	140	182	1.16	41	3.40	21	4.96	14	5.93	11	6.67
	160	208	1.16	47	3.40	24	4.96	16	6.00	12	6.84
	180	234	1.16	53	3.40	27	4.96	18	6.09	13	6.98
	200	260	1.16	59	3.40	30	4.97	20	6.13		1/
	240	312	1.16	71	3.40	36	5.01	23	6.19		
	280		3/	82	3.40	42	5.01	27	6.21		
	320			94	3.40	48	5.03	31	6.22		
	360			106	3.40	54	5.04	35	6.25		
	400			118	3.40	59	5.06	28	6.27		
	440			129	3.40	65	5.07	42	6.29		
	480			141	3.40	71	5.08	46	6.31		
	520			153	3.40	77	5.08	49	6.32		

Drain Area Acres	Q cfs Dsch	Slope = 2.0%									
		d=0.6'		d=0.9'		d=1.2'		d=1.5'		d=1.8'	
		t	v	t	v	t	v	t	v	t	v
	10	50	.50	8	2.00	4	3.50	2	4.16	2	3.63
	20	100	.50	6	2.00	7	3.78	4	4.87	4	4.76
	30	150	.50	25	2.00	10	3.90	6	5.08	5	5.43
	40	200	.50	33	2.00	13	3.96	8	5.26	6	5.64
	50	250	.50	42	2.00	16	4.00	9	5.31	7	5.95
	60	300	.50	50	2.01	19	4.03	11	5.35	8	6.10
	70	--	3/	58	2.01	22	4.05	13	5.42	9	6.27
	80			66	2.01	25	4.06	15	5.48	11	6.35
	90			75	2.01	28	4.07	16	5.48	12	6.47
	100			83	2.01	31	4.08	18	5.49	13	6.51
	120			99	2.02	37	4.09	22	5.52	15	6.67
	140			116	2.02	43	4.10	25	5.56	17	6.74
	160			132	2.02	49	4.11	29	5.57	20	6.80
	180			149	2.02	55	4.12	32	5.59	22	6.80
	200			165	2.02	61	4.12	36	5.60	25	6.80
	240			198	2.02	73	4.13	43	5.62	29	6.89
	280			231	2.02	85	4.13	50	5.63	34	6.89
	320			264	2.02	97	4.14	57	5.64	39	6.89
	360			297	2.02	109	4.14	64	5.65	43	6.90
	400			--	3/	121	4.14	71	5.65	48	6.90
	440					133	4.14	78	5.66	53	6.90
	480					145	4.14	85	5.66	58	6.90
	520					157	4.14	92	5.67	63	6.90

Drain Area Acres	Q cfs Dsch	Slope = 3.0%							
		d=0.6'		d=0.9'		d=1.2'		d=1.5'	
		t	v	t	v	t	v	t	v
	10	30	.83	6	1.50	3	4.03	3	4.00
	20	59	.84	11	3.00	5	4.76	4	5.33
	30	88	.85	16	3.11	8	5.00	5	5.88
	40	117	.85	21	3.17	10	5.13	6	6.55
	50	146	.85	26	3.23	12	5.29	8	6.58
	60	174	.86	31	3.25	14	5.36	9	6.74
	70	203	.86	36	3.27	16	5.38	10	6.86
	80	232	.86	41	3.28	19	5.41	12	6.96
	90	261	.86	46	3.30	21	5.42	--	1/
	100	289	.86	50	3.32	23	5.43		
	120	--	2/	60	3.33	28	5.45		
	140			70	3.33	32	5.47		
	160			80	3.34	37	5.48		
	180			90	3.34	41	5.49		
	200			100	3.34	46	5.50		
	240			120	3.34	55	5.51		
	280			140	3.34	64	5.52		
	320			160	3.34	73	5.52		
	360			180	3.34	82	5.52		
	400			200	3.34	91	5.52		
	440			220	3.34	100	5.52		
	480			240	3.34	109	5.52		
	520			260	3.34	118	5.52		

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example:
Slope = 2% d = 1.2'
Find t & v for Q = 115 cfs
15/20 = .75 this is the proportional part of increment between the respective discharges.
t = 37 - 31 = (6 x .75) + 31 = 36'
v = 4.09 - 4.08 = (.01 x .75) + 4.08 = 4.09 fps
Find "t" & "v" for Q = 100 cfs, Slope = 2.6%, d = 1.2'

Slope = 3%	Slope = 2%
t = 23'	t = 31'
v = 5.43 fps	v = 4.08 fps

For Slope 2.6%, t = 31 - 23 = 8 x .6 = 4.8 + 23 = 27.8'
v = 5.43 - 4.08 = 1.35 x .6 = .81 + 4.08 = 4.89 fps

d = design flow depth
D = dt + 0.5' freeboard
t = design top width from table
T = t + 4 = constructed top width
At D/4 depth the width is T/2
At D/2 depth the width is 0.75T
These are points to be checked during construction.

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)

2/ Approaching Critical discharge

3/ Maximum top width (arbitrary)

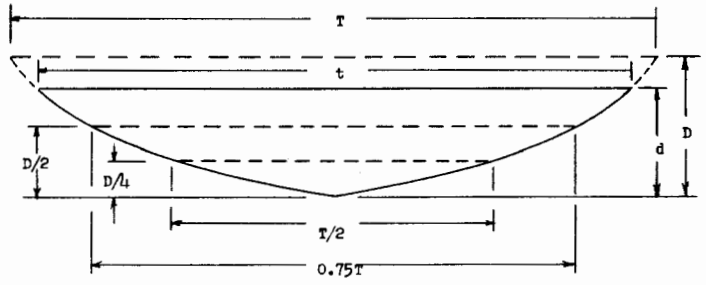


Figure 5.7

PARABOLIC WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "C"

Drain Area Acres	Q cfs Dsch	Slope = 4.0%								Slope = 5.0%								Slope = 6.0%						Slope = 7.0%						Slope = 8.0%				Slope = 9.0%				Slope = 10.0%			
		d=0.6'		d=0.8'		d=1.0'		d=1.2'		d=0.5'		d=0.6'		d=0.7'		d=0.8'		d=0.5'		d=0.6'		d=0.7'		d=0.5'		d=0.6'		d=0.7'		d=0.5'		d=0.6'		d=0.5'		d=0.6'		d=0.5'		d=0.6'	
		t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
	10	17	1.52	6	3.36	3	4.69	2	5.56	40	.75	14	1.75	8	2.77	5	3.61	26	1.13	12	2.17	7	3.25	22	1.40	10	2.48	6	3.80	17	1.74	9	2.94	14	2.10	7	3.45	13	2.30	6	4.00
	20	33	1.52	11	3.38	6	4.92	4	6.25	80	.75	28	1.77	15	2.81	10	3.95	52	1.15	23	2.20	12	3.46	42	1.40	20	2.53	11	3.87	34	1.75	16	3.08	28	2.10	14	3.57	26	2.30	12	4.17
	30	50	1.52	17	3.38	9	5.12	6	6.47	120	.75	42	1.78	23	2.83	14	4.05	78	1.16	34	2.23	18	3.53	64	1.40	30	2.53	16	4.15	51	1.76	24	3.13	43	2.10	21	3.60	39	2.30	18	4.24
	40	66	1.52	22	3.38	12	5.13	8	6.49	160	.75	56	1.78	30	2.86	18	4.11	104	1.16	45	2.23	24	3.55	85	1.40	39	2.54	21	4.16	68	1.76	32	3.15	57	2.10	28	3.60	52	2.30	24	4.26
	50	83	1.52	28	3.39	14	5.21	10	6.58	200	.75	70	1.78	37	2.86	23	4.12	130	1.16	56	2.24	30	3.57	107	1.40	49	2.55	26	4.21	85	1.76	40	3.15	71	2.10	34	3.67	65	2.30	29	4.31
	60	99	1.52	33	3.40	17	5.22	11	6.60	240	.75	84	1.78	45	2.86	27	4.13	156	1.16	67	2.24	36	3.58	128	1.40	59	2.55	31	4.22	102	1.76	47	3.17	85	2.10	41	3.68	78	2.30	35	4.32
	70	116	1.52	39	3.40	20	5.23	13	6.63	280	.75	98	1.78	52	2.86	32	4.14	182	1.16	78	2.24	42	3.59	150	1.40	69	2.55	36	4.22	119	1.76	55	3.17	100	2.10	47	3.69	91	2.30	40	4.35
	80	132	1.52	44	3.40	23	5.26	15	6.71	320	.75	112	1.78	60	2.86	36	4.14	208	1.16	89	2.24	48	3.59	171	1.40	78	2.55	41	4.24	136	1.76	63	3.17	114	2.10	54	3.69	104	2.30		2/
	90	149	1.52	50	3.40	26	5.27	17	6.72	--	3/	126	1.78	67	2.86	41	4.14	234	1.16	100	2.25	54	3.60	193	1.40	88	2.55	--	2/	153	1.76	71	3.18	129	2.10	61	3.69	118	2.30		
	100	165	1.52	56	3.40	29	5.27	19	6.73			140	1.78	75	2.86	46	4.14	260	1.16	111	2.25	60	3.60	214	1.40	98	2.55			170	1.76	79	3.18	143	2.10	68	3.69	131	2.30		
	120	198	1.52	67	3.40	34	5.27	22	6.76			168	1.78	90	2.86	55	4.14	312	1.16	133	2.26	71	3.61	257	1.40	117	2.55			204	1.76	94	3.18	172	2.10	81	3.69	157	2.30		
	140	231	1.52	78	3.40	40	5.27	26	6.78			224	1.78	105	2.86	64	4.14	--	3/	155	2.27	83	3.61	300	1.40	137	2.55			238	1.76	110	3.19	201	2.10	95	3.70	184	2.30		
	160	264	1.52	89	3.40	46	5.27	29	6.80			252	1.78	120	2.86	73	4.14			176	2.27	95	3.61	--	3/	156	2.56			272	1.76	125	3.19	230	2.10	108	3.70	210	2.30		
	180	297	1.52	100	3.40	51	5.27	33	6.81			280	1.78	135	2.86	82	4.14			198	2.27	107	3.61			176	2.56			306	1.76	141	3.20	259	2.10	122	3.70	236	2.30		
	200	--	3/	112	3.40	57	5.27	37	6.83			308	1.78	150	2.86	91	4.14			220	2.27	119	3.61			195	2.56			--	3/	156	3.20	288	2.10	135	3.70	263	2.30		
	240			134	3.40	68	5.27	44	6.85			--	3/	180	2.86	110	4.14			264	2.28	143	3.61			234	2.56					187	3.20	--	3/	162	3.70	316	2.30		
	280			156	3.40	80	5.27	51	6.86					210	2.86	128	4.14			307	2.28	166	3.61			273	2.56					218	3.21			189	3.71	--	3/		
	320			179	3.40	91	5.27	58	6.87					240	2.86	146	4.14			--	3/	190	3.61			312	2.56					249	3.21			216	3.71				
	360			201	3.40	103	5.27	65	6.88					270	2.86	164	4.14					214	3.61			--	3/					280	3.21			243	3.71				
	400			224	3.40	114	5.27	73	6.89					300	2.86	183	4.14					238	3.61									311	3.21			270	3.71				
	440			246	3.40	125	5.27	80	6.89					--	3/	202	4.14					266	3.61									--	3/			296	3.71				
	480			268	3.40	137	5.27	87	6.90							220	4.14					285	3.61													323	3.71				
	520			291	3.40	148	5.27	94	6.90							238	4.14					309	3.61													--	3/				

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 4% d = 1.2'
Find t & v for Q = 390 cfs
30/40 = .75 this is the proportional part of increment between the respective discharges.
t = 73 - 65 = (8 x .75) = + 65 = 71
v = 6.89 - 6.88 = (.01 x .75) + 6.88 = 6.89 fps
Find "t" & "v" for Q = 40, Slope = 4.3%, d = 0.8'

Slope = 5%	Slope = 4%
t = 18	t = 22
v = 4.11	v = 3.38

For Slope = 4.3%, t = 22 - 18 = 4 x .3 = 1.2'
t = 22 - 1.2 = 20.8'
v = 4.11 - 3.38 = .73 x .3 = .22
3.38 + .22 = 3.60 fps

d = design flow depth
D = d + 0.5' freeboard
t = design top width from table
T = t + 4 = constructed top width
At D/4 depth the width is T/2
At D/2 depth the width is 0.75T
These are points to be checked during construction.

1/ Approaching max. vel. 7fps (arb.)

2/ Approaching Critical Discharge

3/ Maximum Top Width (arb)

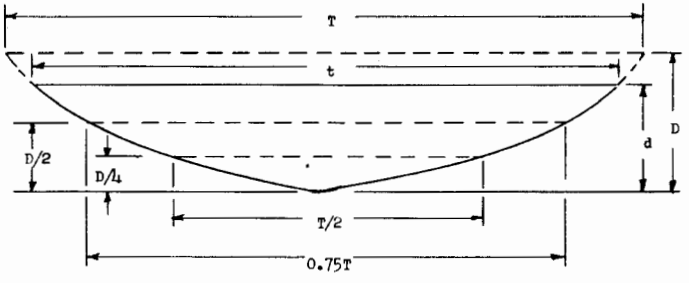


Figure 5.7 (cont'd)

Sheet 1 of 1

PARABOLIC WATERWAY DIMENSION CHART

VEGETATIVE RESISTANCE "D"

Q cfs	Slope = 0.5%								Slope = 1.0%							
	d=1.0'		d=1.5'		d=2.0'		d=2.5'		d=1.0'		d=1.5'		d=2.0'		d=2.5'	
	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
10	11	1.36	4	2.50	3	2.73	2	2.86	7	2.14	3	3.85	2	3.95	2	3.76
20	23	1.33	8	2.50	5	3.13	3	3.50	14	2.22	5	3.85	3	4.55	3	4.81
30	35	1.30	12	2.50	7	3.31	5	3.78	20	2.25	8	3.85	5	4.85	3	5.28
40	46	1.30	16	2.50	9	3.33	6	3.94	27	2.27	10	3.85	6	4.98	4	5.56
50	58	1.30	20	2.50	11	3.35	7	4.05	33	2.28	13	3.85	7	5.07	5	5.76
60	69	1.30	24	2.50	13	3.41	9	5.12	40	2.28	16	3.85	9	5.13	6	5.88
70	80	1.30	28	2.50	15	3.46	10	4.17	46	2.28	18	3.85	10	5.17	7	5.98
80	93	1.30	32	2.50	17	3.47	11	4.21	53	2.28	21	3.85	12	5.20	8	6.05
90	104	1.30	36	2.50	19	3.47	13	4.24	60	2.28	23	3.85	13	5.23	9	6.11
100	115	1.30	40	2.50	22	3.48	14	4.26	66	2.28	26	3.85	14	5.25	10	6.16
120	138	1.30	48	2.50	26	3.50	17	4.30	79	2.28	31	3.85	17	5.28	12	6.26
140	162	1.30	56	2.50	30	3.51	19	4.33	92	2.28	36	3.85	20	5.30	13	6.33
160	185	1.30	64	2.50	34	3.52	22	4.35	106	2.28	42	3.85	23	5.32	15	6.38
180	208	1.30	72	2.50	38	3.53	25	4.37	118	2.28	47	3.85	25	5.33	17	6.42
200	231	1.30	80	2.50	43	3.53	27	4.38	132	2.28	52	3.85	28	5.34	19	6.46
240	3/		96	2.50	49	3.69	33	4.40	158	2.28	62	3.85	34	5.36	22	6.51
280			112	2.50	55	3.82	38	4.42	184	2.28	73	3.85	39	5.37	26	6.55
320			128	2.50	61	3.92	43	4.43	210	2.28	83	3.85	45	5.38	29	6.58
360			144	2.50	68	4.00	49	4.44	3/		94	3.85	50	5.38	33	6.60
400			160	2.50	74	4.06	54	4.45			104	3.85	56	5.40	36	6.62
440			176	2.50	80	4.12	59	4.45			114	3.85	61	5.40	40	6.63
480			192	2.50	87	4.17	65	4.46			125	3.85	67	5.40	43	6.65
520			208	2.50	93	4.21	70	4.46			135	3.85	72	5.41	47	6.66

Q cfs	Slope = 2.0%								Slope = 3.0%									
	d=0.5'		d=0.7'		d=1.0'		d=1.5'		d=0.5'		d=0.6'		d=0.7'		d=0.8'		d=0.9'	
	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v	t	v
10	28	1.09	10	2.15	4	3.75	2	4.17	19	1.56	12	2.18	8	2.86	6	3.36	4	3.99
20	55	1.09	20	2.15	8	3.75	5	4.17	38	1.58	23	2.21	15	2.96	11	3.58	8	4.17
30	82	1.10	30	2.16	12	3.75	7	4.17	57	1.59	34	2.23	22	2.99	15	3.68	12	4.24
40	109	1.10	39	2.18	16	3.75	10	4.17	75	1.60	45	2.23	29	3.01	20	3.71	16	4.27
50	137	1.10	49	2.18	20	3.75	12	4.17	94	1.60	58	2.24	36	3.02	25	3.72	19	4.29
60	164	1.10	59	2.19	24	3.75	14	4.17	113	1.60	67	2.25	43	3.03	30	3.74	23	4.31
70	191	1.10	69	2.19	28	3.75	17	4.17	131	1.60	78	2.25	50	3.03	35	3.74	27	4.32
80	218	1.10	78	2.19	32	3.75	19	4.17	150	1.60	89	2.25	57	3.04	40	3.75	31	4.33
90	245	1.10	88	2.19	36	3.75	22	4.17	169	1.60	100	2.26	64	3.04	45	3.75	35	4.33
100	273	1.10	98	2.19	40	3.75	24	4.17	188	1.60	111	2.26	71	3.04	50	3.76	38	4.34
120	3/		117	2.20	48	3.75		2/	225	1.60	133	2.26	85	3.05	60	3.76	46	4.35
140			136	2.20	56	3.75			263	1.60	155	2.26	99	3.05	70	3.77	54	4.35
160			155	2.21	64	3.75			300	1.60	177	2.26	113	3.05	80	3.77	61	4.36
180			175	2.21	72	3.75			3/		199	2.26	127	3.05	90	3.77	69	4.36
200			194	2.21	80	3.75					221	2.27	141	3.05	99	3.77	76	4.36
240			232	2.22	96	3.75					265	2.27	169	3.06	119	3.78	92	4.37
280		3/			112	3.75					309	2.27	197	3.06	139	3.78	107	4.37
320					128	3.75					3/		225	3.06	159	3.78	122	4.37
360					144	3.75							253	3.06	179	3.78	137	4.37
400					160	3.75							281	3.06	198	3.78	152	4.37
440					176	3.75							309	3.06	218	3.78	168	4.37
480					192	3.75							3/		238	3.78	183	4.37
520					208	3.75									258	3.78	198	4.38

Q cfs	Slope = 4.0%								Slope = 5.0%							
	d=0.5'		d=0.6'		d=0.7'		d=0.8'		d=0.5'		d=0.6'		d=0.7'			
	t	v	t	v	t	v	t	v	t	v	t	v	t	v		
10	15	2.09	9	2.94	6	3.82	4	4.46	12	2.54	7	3.45	5	4.29		
20	29	2.10	17	2.94	11	3.82	8	4.58	24	2.54	14	3.51	10	4.38		
30	43	2.10	26	2.94	17	3.82	12	4.61	36	2.54	21	3.53	15	4.41		
40	58	2.10	34	2.94	22	3.82	16	4.68	47	2.54	28	3.54	19	4.42		
50	72	2.11	43	2.94	28	3.82	20	4.69	59	2.54	35	3.55	24	4.43		
60	86	2.11	51	2.94	34	3.82	2/		71	2.54	42	3.55	29	4.43		
70	100	2.11	60	2.94	39	3.82			83	2.55	49	3.55	34	4.44		
80	115	2.11	68	2.94	45	3.82			95	2.55	56	3.56	39	4.45		
90	129	2.11	77	2.94	51	3.82			106	2.55	63	3.56		2/		
100	143	2.11	85	2.94	56	3.82			118	2.55	70	3.56				
120	172	2.11	102	2.94	67	3.82			141	2.55	84	3.56				
140	201	2.11	119	2.94	79	3.82			165	2.55	98	3.56				
160	230	2.11	136	2.94	90	3.82			188	2.55	112	3.56				
180	259	2.11	153	2.94	100	3.82			212	2.55	126	3.56				
200	287	2.11	170	2.94		2/			235	2.55	140	3.57				
240	345	2.11	204	2.94					282	2.55	168	3.57				
280	3/		238	2.94					329	2.55	196	3.57				
320			272	2.94					3/		224	3.57				
360			306	2.94							252	3.57				
400			3/								280	3.57				
440											308	3.57				
480											3/					
520																

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example:
Slope = 3.0%, d = 0.8'
Find "d" & "v" for Q = 290 cfs
10/40 = .25 this is the proportional part of increment between the respective discharges
t = 159 - 139 = (20 x .25) + 139 = 144'
v = 3.78 - 3.78 = (0 x .25) + 3.78 = 3.78 fps
Find "t" & "v" for Q = 160 cfs, Slope = 3.7%, d = 0.7'

Slope = 3%	Slope = 4%
t = 113'	t = 90'
v = 3.05 fps	v = 3.82 fps

For Slope 3.7%, t = 113 - 90 = 23
t = .7 x 23 = .16, 113 - 16 = 97'
v = 3.82 - 3.05 = .77
v = .7 x .77 = .54, 3.05 + .54 = 3.59 fps

d = design flow depth
T = t + 4' = constructed top width
t = design top width from table
At D/4 depth, the width is T/2
At D/2 depth, the width is 0.75T
These are points to be checked during construction.

Remarks:
1/ Approaching maximum velocity 7 fps (arbitrary)
2/ Approaching critical discharge
3/ Maximum top width (arbitrary)

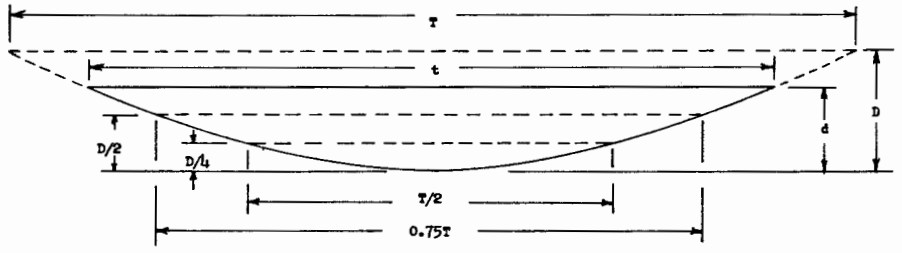


Figure 5.8

TRIANGULAR WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "A"

Drain Area Acres	Q cfs Dsch	Slope = 0.5%								Slope = 1.0%								Slope = 1.5%								Slope = 2.0%							
		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4	
		d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v
	10			3.47	.41	2.99	.37	2.71	.34	3.98	.63	3.02	.55	2.58	.50	2.31	.47	3.54	.75	2.75	.66	2.35	.58	2.17	.53	3.43	.85	2.53	.78	2.24	.66	2.00	.62
	20			-	-	3.74	.47	3.38	.43	-	-	3.67	.77	3.16	.66	2.87	.60	3.97	1.26	3.11	1.03	2.69	.92	2.52	.79	3.83	1.36	2.87	1.21	2.65	.94	2.46	.83
	30			3/		-	-	3.76	.53	3/		3/	-	3.49	.82	3.23	.74	3/		3.32	1.36	2.90	1.18	2.72	1.01	3/		3.08	1.60	2.84	1.23	2.64	1.08
	40					3/		-	-					3.68	.98	3.43	.84			3.48	1.66	3.06	1.42	2.86	1.22			3.24	1.90	2.95	1.53	2.76	1.31
	50							3/						3.82	1.14	3.51	1.01			3.61	1.91	3.18	1.64	2.98	1.40			3.36	2.21	3.04	1.80	2.84	1.54
	60													3.90	1.34	3.57	1.17			3.74	2.14	3.29	1.84	3.08	1.58			3.47	2.49	3.12	2.05	2.92	1.75
	70													3.95	1.49	3.63	1.32			3.84	2.37	3.39	2.03	3.16	1.75			3.57	2.74	3.21	2.86	2.98	1.99
	80													3.98	1.68	3.68	1.47			3.93	2.58	3.48	2.20	3.23	1.91			3.66	2.98	3.26	2.50	3.04	2.16
	90													4.00	1.87	3.74	1.60			4.00	2.81	3.55	2.38	3.30	2.06			3.75	3.19	3.34	2.68	3.10	2.34
	100													- 3/	-	3.80	1.73			3/		3.62	2.54	3.37	2.20			3.83	3.40	3.41	2.86	3.16	2.50
	120															3.92	1.95					3.77	2.81	3.49	2.46			3.98	3.78	3.52	3.22	3.27	2.80
	140															- 3/	-					3.92	3.03	3.60	2.70			3/		3.63	3.54	3.37	3.08
	160																					3/		3.70	2.92					3.74	3.81	3.46	3.34
	180																							3.80	3.22					3.84	4.06	3.55	3.57
	200																							3.89	3.30					3.94	4.29	3.64	3.77
	240																							3/						3/		3.80	4.15
	280																															3.95	4.34
	320																															3/	
	360																																
	400																																
	440																																
	480																																
	520																																

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 1.5% z = 3
Find d & v for Q = 85 cfs
5/10 = .50 this is the proportional part of increment between the respective discharges.
d = 3.55 - 3.48 = (.07 x .50) + 3.48 = 3.52'
v = 2.38 - 2.20 = (.18 x .50) + 2.20 = 2.29 fps
Find "d" & "v", Q = 80 cfs, Slope = 1.2% z = 3
Slope = 1.0% Slope = 1.5%
d = 3.98' d = 3.48'
v = 1.68 fps v = 2.20 fps
For Slope 1.2%, d = 3.98 - 3.48 = 0.50'
d = .50 x .4 = 0.20', d = 3.98 - .20 = 3.78'
v = 2.20 - 1.68 = .52 fps
v = .52 x .4 = .21, 1.68 + .21 = 1.89 fps
Use same method of interpolation for values of z between those shown on the chart.

d = design flow depth
D = d + 0.5' freeboard
t = 2zd = design top width
T = 2zD = constructed top width
Read d & v from table
Compute d & v for constructed dimensions

Remarks: 1/ Approaching Maximum Velocity 7fps (arbitrary)

2/ Approaching Critical Discharge

3/ Max. depth (arbitrary) 4.0'

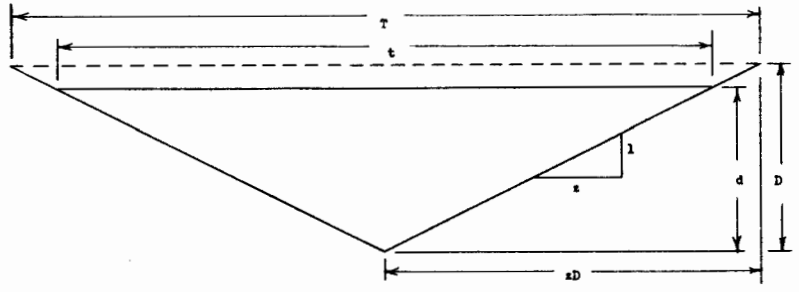


Figure 5.9

TRIANGULAR WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "B"

Drain Area Acres	Q cfs Dsch	Slope = 0.5%								Slope = 1.0%								Slope = 1.5%								Slope = 2.0%							
		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4	
		d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v
	10	3.45	.83	2.79	.64	2.38	.58	2.18	.52	2.75	1.31	2.27	.96	2.04	.80	1.91	.68	2.65	1.42	2.00	1.25	1.79	1.04	1.66	.90	2.48	1.62	1.89	1.39	1.80	1.20	1.60	1.04
	20	3.95	1.28	3.05	1.07	2.72	.90	2.50	.80	3.38	1.74	2.56	1.52	2.29	1.27	2.13	1.10	3.02	2.19	2.24	1.99	2.03	1.61	1.87	1.42	2.90	2.37	2.18	2.10	1.90	1.82	1.80	1.61
	30	1/		3.29	1.38	2.82	.83	2.73	1.00	3.70	2.19	2.79	1.92	2.48	1.62	2.31	1.40	3.30	2.75	2.49	2.41	2.21	2.04	2.03	1.81	3.13	3.06	2.37	2.66	2.10	2.28	1.90	2.05
	40			3.50	1.63	3.10	1.38	2.88	1.20	3.95	2.56	3.01	2.20	2.62	1.94	2.42	1.70	3.53	3.21	2.65	2.84	2.37	2.37	2.17	2.12	3.31	3.64	2.53	3.13	2.20	2.70	2.00	2.45
	50			3.69	1.83	3.25	1.57	3.01	1.37	1/		3.16	2.50	2.75	2.20	2.53	1.95	3.73	3.59	2.80	3.18	2.48	2.71	2.28	2.40	3.50	4.00	2.67	3.50	2.40	3.01	2.10	2.83
	60			3.85	2.02	3.37	1.76	3.12	1.54			3.30	2.75	2.87	2.42	2.64	2.15	3.92	3.90	2.93	3.49	2.57	3.02	2.37	2.67	3.66	4.47	2.82	3.77	2.40	3.39	2.20	3.04
	70			1/		3.49	1.91	3.20	1.70			3.44	2.95	2.98	2.62	2.75	2.31	1/		3.06	3.73	2.67	3.27	2.44	2.93	3.85	4.72	3.91	4.13	2.50	3.67	2.30	3.30
	80					3.56	2.10	3.29	1.84			3.53	3.21	3.07	2.82	2.83	2.49			3.18	3.91	2.77	3.47	2.52	3.14	3.98	5.05	3.01	4.41	2.60	3.91	2.40	3.53
	90					3.66	2.23	3.39	1.95			3.64	3.39	3.19	2.94	2.94	2.60			3.26	4.23	2.85	3.69	2.60	3.32	1/		3.10	4.75	2.70	4.20	2.50	3.74
	100					3.77	2.34	3.47	2.07			3.74	3.57	3.27	3.11	3.00	2.77			3.35	4.45	2.91	3.93	2.67	3.50			3.19	4.91	2.80	4.34	2.50	3.96
	120					3.85	2.69	3.62	2.32			3.83	4.08	3.42	3.41	3.14	3.04			3.54	4.78	3.05	4.29	2.80	3.83			3.35	5.34	2.90	4.75	2.6	4.33
	140					1/		3.77	2.46			1/		3.56	3.68	3.27	3.27			3.72	5.05	3.20	4.55	2.92	4.12			3.50	5.71	3.00	5.11	2.80	4.62
	160							3.91	2.61					3.70	3.89	3.38	3.50			3.85	5.39	3.32	4.83	3.03	4.35			3.65	6.00	3.10	5.40	2.90	4.88
	180							1/						3.80	4.15	3.48	3.71			1/		3.45	5.04	3.13	4.59			3.78	6.29	3.30	5.68	3.00	5.13
	200													3.91	4.36	3.56	3.94					3.53	5.35	3.23	4.79			3.90	6.57	3.40	5.94	3.10	5.37
	240													1/		3.75	4.26					3.75	5.68	3.41	5.16			1/		3.50	6.38	3.20	5.78
	280															3.85	4.72					3.93	6.04	3.57	5.49					3.70	6.78	3.40	6.20
	320															3.94	5.15					1/		3.72	5.78					1/		3.50	6.44
	360															1/								3.87	6.00							3.70	6.75
	400																							3.99	6.28							3.80	7.00
	440																							1/									1/
	480																																
	520																																

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 2% z = 4
Find d & v for Q = 75 cfs
5/10 = .50 this is the proportional part of increment between the respective discharges.
d = 2.40 - 2.30 = (.10 x .50) + 2.30 = 2.40'
v = 3.53 - 3.30 = (.23 x .50) + 3.30 = 3.43 fps
Find "d" & "v" Q = 180, z = 3, Slope = 1.8%
Slope 1.5% Slope 2.0%
d = 3.45 d = 3.30
v = 5.04 v = 5.68
Slope 1.8%, b = 3.45 - 3.30 = .15
b = .15 x .6 = .09, 3.45 - .09 = 3.36'
v = 5.68 - 5.04 = 0.64
v = .64 x .6 = 38 v = 5.04 + .38 = 5.42 fps
Use same method of interpolation for the values of z between those shown on this chart.

d = design flow depth
D = d + 0.5' freeboard
t = 2zd = design top width
T = 2zD = constructed top width
Read d & v from table
Compute d & v for constructed top width

Remarks: 1/ Approaching Maximum Velocity 7fps (arbitrary)

2/ Approaching Critical Discharge

3/ Max. depth (arbitrary) 4.0'

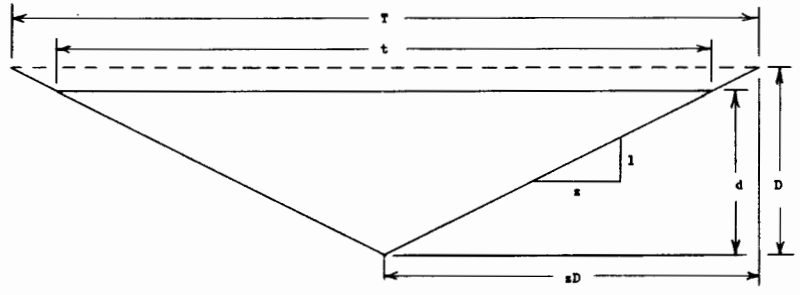


Figure 5.10

TRIANGULAR WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "C"

Drain Area Acres	# cfs Dsch	Slope = 0.5%								Slope = 1.0%								Slope = 1.5%								Slope = 2.0%							
		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4	
		d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v
	10	2.63	1.45	2.11	1.12	1.78	1.06	1.65	.92	2.09	2.29	1.74	1.65	1.48	1.52	1.36	1.36	1.90	2.81	1.53	2.07	1.31	1.95	1.22	1.69	1.82	3.02	1.45	2.36	1.26	2.13	1.18	1.80
	20	3.07	2.12	2.40	1.73	2.05	1.58	1.89	1.40	2.55	3.07	2.05	2.47	1.72	2.25	1.58	2.00	2.29	3.81	1.81	3.05	1.53	2.84	1.41	2.52	2.15	4.32	1.73	3.34	1.46	3.13	1.35	2.75
	30	3.40	2.59	2.60	2.21	2.24	1.99	2.07	1.75	2.90	3.56	2.26	2.93	1.88	2.72	1.75	2.44	2.61	4.40	2.03	3.65	1.70	3.46	1.56	3.08	2.43	5.08	1.93	4.03	1.62	3.81	1.48	3.42
	40	3.67	2.96	2.78	2.59	2.39	2.33	2.21	2.05	3.16	4.00	2.42	3.41	2.02	3.26	1.88	2.82	2.86	4.89	2.20	4.12	1.85	3.78	1.69	3.50	2.70	5.49	2.10	4.54	1.76	4.30	1.60	3.91
	50	3.90	3.24	2.94	2.89	2.53	2.60	2.33	2.30	3.38	4.37	2.55	3.84	2.16	3.57	1.98	3.20	3.08	5.27	2.34	4.57	1.97	4.29	1.79	3.90	2.91	5.90	2.23	5.03	1.86	4.82	1.70	4.32
	60	3/		3.08	3.16	2.66	2.82	2.43	2.54	3.57	4.70	2.65	4.27	2.28	3.84	2.08	3.46	3.27	5.60	2.46	4.95	2.08	4.62	1.89	4.19	3.10	6.24	2.35	5.43	1.97	5.15	1.79	4.68
	70			3.21	3.39	2.77	3.04	2.53	2.73	3.74	5.00	2.78	4.52	2.39	4.08	2.17	3.71	3.43	5.85	2.57	5.30	2.18	4.90	1.97	4.50	3.23	6.70	2.44	5.88	2.06	5.72	1.85	5.11
	80			3.34	3.58	2.86	3.25	2.62	2.91	3.90	5.19	2.89	4.75	2.48	4.33	2.26	3.91	3.58	6.24	2.67	5.61	2.28	5.13	2.04	4.80	3.40	6.92	2.54	6.20	2.15	5.77	1.95	5.25
	90			3.46	3.75	2.97	3.40	2.71	3.06	3/		2.99	5.03	2.57	4.54	2.33	4.14	3.73	6.47	2.76	5.91	2.36	5.39	2.12	5.00		2/	2.63	6.81	2.23	6.03	2.02	5.51
	100			3.59	3.87	3.06	3.55	2.79	3.21			3.10	5.20	2.66	4.71	2.40	4.34	3.87	6.67	2.85	6.15	2.44	5.60	2.19	5.21			2.71	6.81	2.31	6.25	2.08	5.78
	120			3.80	4.15	3.24	3.80	2.94	3.47			3.30	5.50	2.82	5.02	2.54	4.64	3/		3.03	6.54	2.58	6.14	2.32	5.57				2/	2.42	6.83	2.21	6.15
	140			4.00	4.37	3.41	4.01	3.08	3.69			3.46	5.24	2.96	5.32	2.66	4.94			3.20	6.84	2.72	6.31	2.45	5.83					2.58	7.00	2.33	6.45
	160			3/		3.56	4.20	3.21	3.88			3.62	6.10	3.09	5.58	2.78	5.17				2/	2.85	6.57	2.56	6.10						2/		1/
	180					3.70	4.38	3.33	4.06			3.77	6.33	3.22	5.76	2.89	5.38					2.96	6.85	2.66	6.36								
	200					3.82	4.56	3.45	4.20			3.92	6.50	3.34	5.97	2.99	5.59						1/	2.76	6.56								
	240					3/		3.67	4.45			3/		3.56	6.30	3.19	5.89							2.94	6.94								
	280							3.87	4.67					3.78	6.53	3.36	6.20								2/								
	320							3/						3.99	6.72	3.52	6.45																
	360													3/		3.67	6.67																
	400															3.82	6.85																
	440															3/																	
	480																																
	520																																

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 1.0 z = 3
Find d & v for Q = 110 cfs
10/20 = .50 this is the proportional part of increment between the respective discharges.
d = 2.82 - 2.66 = (.16 x .50) + 2.66 = 2.74'
v = 5.02 - 4.71 = (.31 x .50) + 4.71 = 4.86 fps
Find "d" & "v" for Q = 200 cfs, z = 4, Slope = 1.4%
Slope 1.0% Slope 2.0%
d = 2.99' d = 2.76'
v = 5.59 fps v = 6.56 fps
For Slope 1.4% d = 2.99 - 2.76 = .23
d = .23 x .8 = .18 d = 2.99 - .18 = 2.81
v = 6.56 - 5.59 = 0.97
v = 0.97 x .8 = .78 v = 5.59 + .78 = 6.37 fps
Use same method of interpolating for the values of z between those shown on this chart.

d = design flow depth
D = d + 0.5' freeboard
t = 2zd = design top width
T = 2zD = constructed top width
Read d & v from table
Compute d & v for constructed top width

Remarks: 1/ Approaching Maximum Velocity 7 fps (arbitrary)

2/ Approaching Critical Discharge

3/ Max. depth (arbitrary) 4.0'

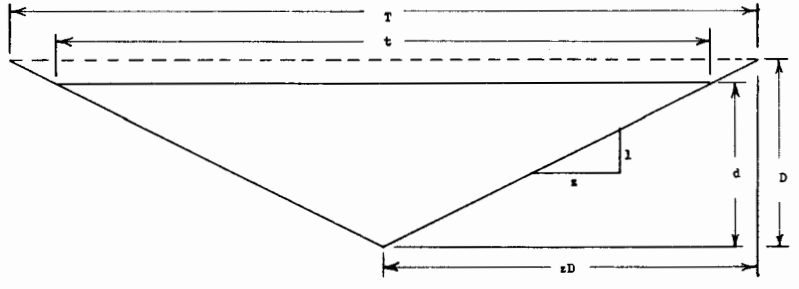


Figure 5.11

TRIANGULAR WATERWAY DIMENSION CHART

VEGETATIVE RETARDANCE "D"

Drain Area Acres	Q cfs Dsch	Slope = 0.5%								Slope = 1.0%								Slope = 1.5%								Slope = 2.0%							
		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4		z = 1		z = 2		z = 3		z = 4	
		d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v	d	v
	10	2.26	1.96	1.73	1.66	1.50	1.48	1.37	1.33	2.00	2.51	1.50	2.23	1.26	2.10	1.17	1.72	1.79	3.13	1.37	2.67	1.19	1.80	1.00	2.50	1.72	3.38	1.28	3.05				
	20	2.31	2.53	2.10	2.25	1.84	1.96	1.65	1.83	2.44	3.35	1.83	2.98	1.54	2.80	1.41	2.51	2.19	4.16	1.67	3.60	1.43	3.25	1.30	2.95	2.11	4.49	1.58	4.00	1.34	3.72	1.23	3.31
	30	3.20	2.92	2.38	2.64	2.07	2.33	1.86	2.16	2.78	3.88	2.06	3.53	1.76	3.22	1.60	2.60	2.51	4.76	1.89	4.19	1.62	3.80	1.46	3.51	2.40	5.21	1.79	4.68	1.53	4.27	1.38	3.93
	40	3.50	3.26	2.59	2.93	2.25	2.63	2.02	2.45	3.06	4.25	2.26	3.91	1.93	3.57	1.76	3.22	2.80	5.10	2.07	4.66	1.78	4.20	1.60	3.90	2.64	5.74	1.96	5.21	1.68	4.72	1.52	4.33
	50	3.76	3.53	2.78	3.23	2.40	2.99	2.16	2.67	3.27	4.67	2.43	4.23	2.08	3.85	1.38	3.53	3.01	5.51	2.22	5.07	1.91	4.56	1.72	4.22	2.85	6.16	2.10	5.67	1.80	5.14	1.63	4.70
	60	4.00	3.75	2.95	3.44	2.53	3.12	2.29	2.85	3.47	4.98	2.59	4.50	2.20	4.13	1.98	3.32	3.20	5.85	2.36	5.38	2.02	4.90	1.82	4.52	3.03	6.54	2.24	5.98	1.91	5.48	1.73	5.01
	70	3/		3.11	3.61	2.66	3.29	2.40	3.03	3.66	5.22	2.71	4.76	2.31	4.37	2.08	4.04	3.35	6.23	2.49	5.64	2.12	5.18	1.91	4.80	3.19	6.88	2.35	6.33		2/	1.81	5.34
	80			3.24	3.80	2.77	3.47	2.50	3.20	3.82	5.48	2.83	4.99	2.41	4.58	2.17	4.24	3.49	6.56	2.60	5.91	2.22	5.40	2.00	5.00		1/		2/			1.39	5.60
	90			3.36	3.98	2.88	3.61	2.60	3.32	3.98	5.68	2.94	5.20	2.50	4.30	2.26	4.40	3.61	6.90	2.71	6.12	2.30	5.67	2.07	5.22							1.97	5.78
	100			3.49	4.10	2.98	3.75	2.69	3.45	3/		3.05	5.37	2.59	4.96	2.34	4.56		1/	2.81	6.33	2.38	5.38	2.14	5.45								2/
	120			3.71	4.35	3.16	4.00	2.85	3.69			3.24	5.71	2.75	5.28	2.48	4.87			2.98	6.75	2.54	6.19	2.28	5.76								
	140			3.90	4.60	3.33	4.20	3.00	3.38			3.41	6.01	2.90	5.54	2.61	5.13				1/	2.66	6.59	2.40	6.07								
	160			3/		3.48	4.40	3.13	4.08			3.56	6.31	3.04	5.76	2.72	5.40					2.79	6.85	2.50	6.40								
	180					3.62	4.57	3.26	4.23			3.71	6.53	3.16	6.00	2.84	5.57						1/	2.61	6.60								
	200					3.75	4.74	3.37	4.40			3.84	6.66	3.26	6.27	2.94	5.78							2.71	6.80								
	240					3.99	5.02	3.59	4.65			3/		3.48	6.60	3.13	6.12							2/									
	280					3/		3.78	4.39					3.67	6.92	3.30	6.42																
	320							3.97	5.07						1/	3.46	6.68																
	360							3/								3.60	6.94																
	400																1/																
	440																																
	480																																
	520																																

Note: To interpolate on this chart use a straight line ratio between the respective discharges. Example
Slope = 1.5 z = 3
Find d & v for Q = 95 cfs
5/10 = .50 this is the proportional part of increment between the respective discharges.
d = 2.38 - 2.30 = (.08 x .50) + 2.30 = 2.34'
v = 5.88 - 5.67 = (.21 x .50) + 5.67 = 5.78 fps
Find "d" & "v" for Q = 100 cfs, Slope = 1.3% z = 4'

Slope = 1.0%	Slope = 1.5%
d = 2.34'	d = 2.14'
v = 4.56 fps	v = 5.45 fps

For Slope 1.3% d = 2.34 - 2.14 = .20
d = .20 x .6 = .12, d = 2.34 - .12 = 2.22'
v = 5.45 - 4.56 = .89
v = .89 x .6 = .53, v = 4.56 + .53 = 5.09 fps
Use same method of interpolation for values of z between those shown on the chart.

d = design flow depth
D = d + 0.5' freeboard
t = 2zd = design top width
T = 2zD constructed top width
Read d & v from table
Compute d & v for constructed top width

Remarks:
1/ Approaching Maximum Velocity 7 fps (arbitrary)
2/ Approaching Critical Discharge
3/ Max. depth (arbitrary) 4.0'

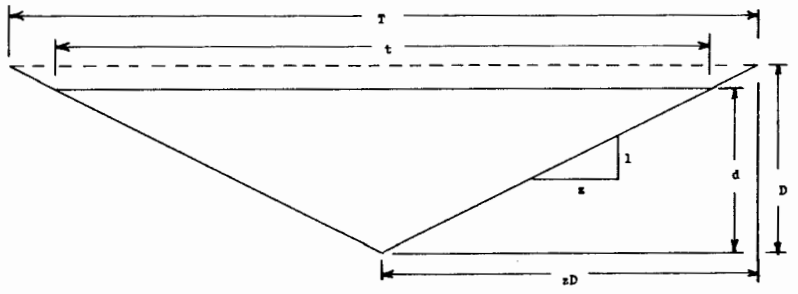


Figure 5.12

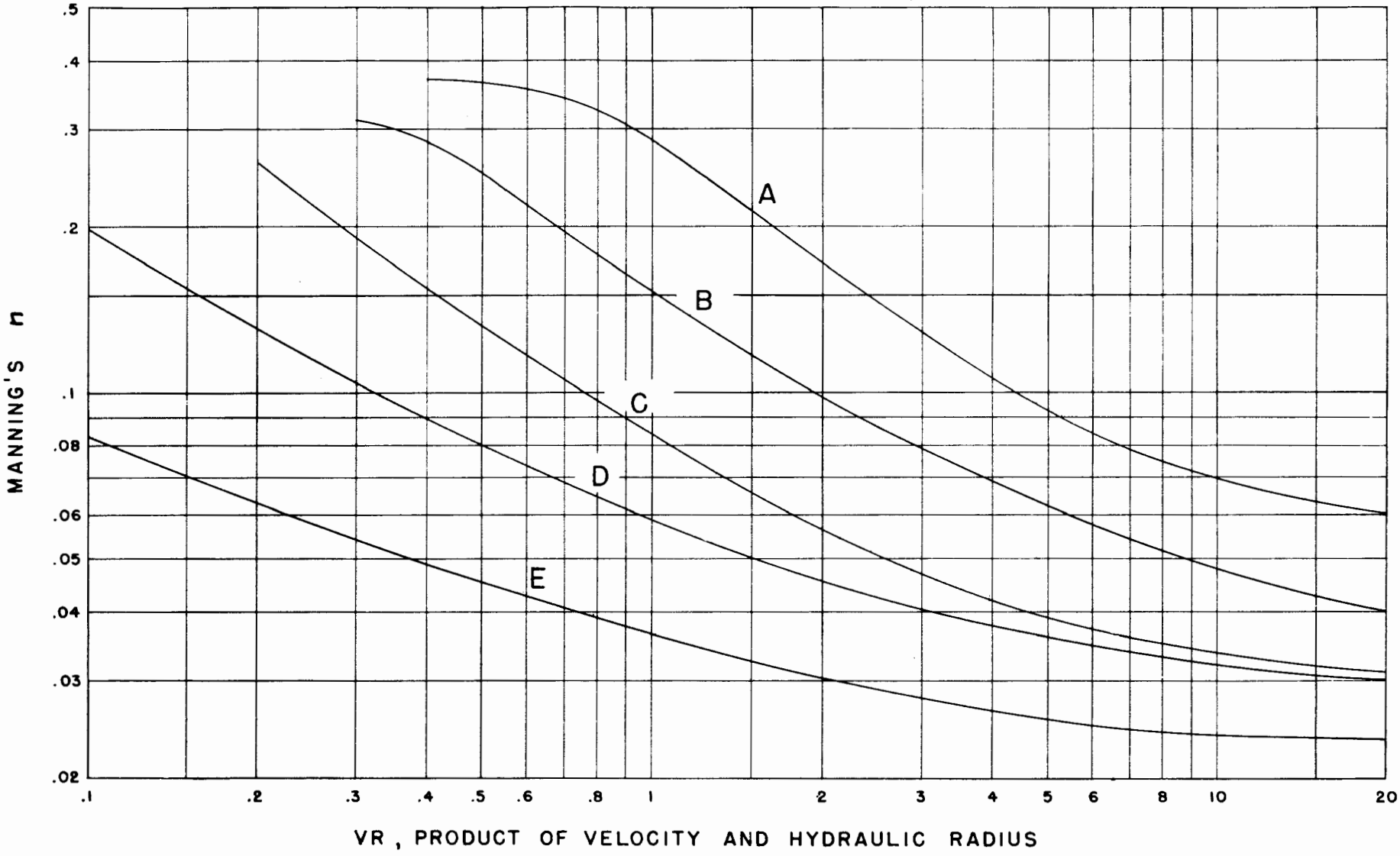
Permissible Velocities for Channels Lined With Vegetation 1/

The Values Apply to Average, Uniform Stands of Each Type of Cover

Cover	Slope range 2/	Permissible velocity	
		Erosion resistant soils	Easily eroded soils
	Percent	Ft. per sec.	Ft. per sec.
Bermudagrass	0-5	8	6
	5-10	7	5
	over 10	6	4
Buffalograss, Kentucky bluegrass, Smooth brome, Blue grama	0-5	7	5
	5-10	6	4
	over 10	5	3
Grass mixture	2/ 0-5	5	4
	5-10	4	3
Lespedeza sericea, Weeping lovegrass, Yellow bluestem, Kudzu, Alfalfa, Crabgrass	3/ 0-5	3.5	2.5
Common lespedeza 4/, Sudangrass 4/	5/ 0-5	3.5	2.5

1/ Use velocities exceeding 5 feet per second only where good covers and proper maintenance can be obtained.
2/ Do not use on slopes steeper than 10 percent except for side slopes in a combination channel.
3/ Do not use on slopes steeper than 5 percent except for side slopes in a combination channel.
4/ Annuals--used on mild slopes or as temporary protection until permanent covers are established.
5/ Use on slopes steeper than 5 percent is not recommended.

Figure 5.13



MANNING'S "n" RELATED TO VELOCITY, HYDRAULIC RADIUS, AND VEGETAL RETARDANCE.

Fig. 5.14

Classification of Vegetation Covers as to Degree of Retardance

Note: Covers Classified Have Been Tested in Experimental Channels. Covers Were Green and Generally Uniform.

Retardance	Cover	Condition
A	Weeping lovegrass.....	Excellent stand, tall (average 30 inches)
	Yellow bluestem Ischaemum	Excellent stand, tall (average 36 inches)
B	Kudzu	Very dense growth, uncut
	Bermudagrass	Good stand, tall (average 12 inches)
	Native grass mixture (little bluestem, blue grama, and other long and short midwest grasses).....	Good stand, unmowed
	Weeping lovegrass.....	Good stand, tall (average 24 inches)
	Lespedeza sericea.....	Good stand, not woody, tall (average 19 inches)
	Alfalfa.....	Good stand, uncut (average 11 inches)
	Weeping lovegrass.....	Good stand, mowed (average 13 inches)
	Kudzu.....	Dense growth, uncut
	Blue grama.....	Good stand, uncut (average 13 inches)
C	Crabgrass.....	Fair stand, uncut (10 to 48 inches)
	Bermudagrass.....	Good stand, mowed (average 6 inches)
	Common lespedeza.....	Good stand, uncut (average 11 inches)
	Grass-legume mixture--summer (orchard grass, redtop, Italian ryegrass, and common lespedeza.....	Good stand, uncut (6 to 8 inches)
	Centipedegrass.....	Very dense cover (average 6 inches)
	Kentucky bluegrass.....	Good stand, headed (6 to 12 inches)
D	Bermudagrass.....	Good stand, cut to 2.5-inch height
	Common lespedeza.....	Excellent stand, uncut (average 4.5 inches)
	Buffalograss.....	Good stand, uncut (3 to 6 inches)
	Grass-legume mixture--fall, spring (Orchardgrass, redtop, Italian ryegrass, and common lespedeza).....	Good stand, uncut (4 to 5 inches)
	Lespedeza sericea.....	After cutting to 2-inch height. Very good stand before cutting.
E	Bermudagrass.....	Good stand, cut to 1.5-inch height
	Bermudagrass.....	Burned stubble.

Figure 5.15

3. DESIGN (CONT'D)

The Waterway Drainage Channel Combination (cont'd)

With Permanent Trickle Channel (cont'd)

or one-half round pipe. Such a channel normally is designed to take a minimum of 25% of the 10-year frequency peak flow. This type of control, which combines vegetation with permanent materials to form a channel, should be adapted in those sections where the slope reaches the point that vegetation alone cannot be considered safe.

With Tile Drain. Tile drainage of waterways is essential where waterways tend to be wet and in areas where tile is recommended generally. Tile drainage also may be needed in some well-drained soils where seepage occurs in the waterway. A well-drained waterway is essential to permit the most economical operation of the field and to prevent damage to the waterway when crossing it with equipment.

Broken tile in waterways must be repaired. In some cases, it may be necessary to abandon old tile because of poor conditions or because of inadequate depth. New tile should be laid immediately following grading of the watercourse. Tile lines should be laid to one side of the watercourse at sufficient depth so that any laterals will have a minimum cover of 2.5 feet at the low point in the waterway. Tile lines should outlet at a permanent structure or by use of corrugated pipe, as illustrated by Figure 5.16. This should be provided where the water disposal system changes from tile and a broad shallow vegetated watercourse to an open drainage ditch.

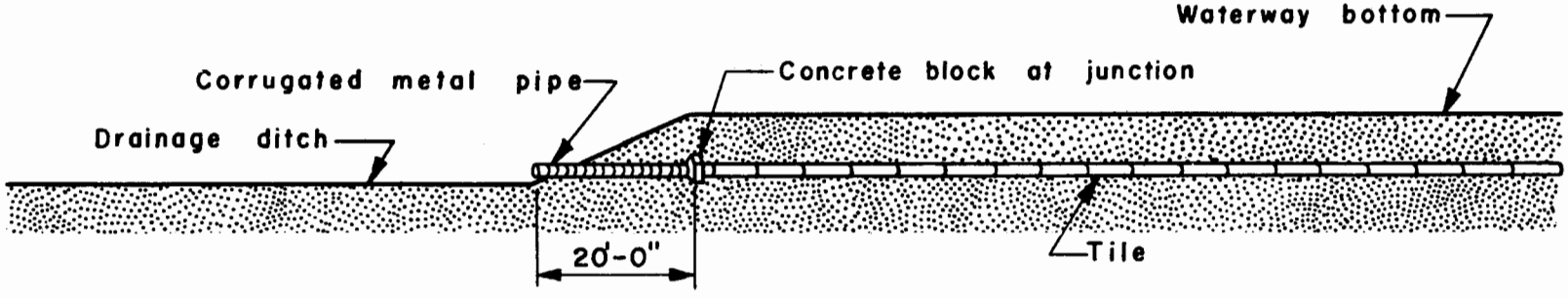
When plans for sub-drainage are completed, actual work on grading of the watercourse is ready to start.

With Open Ditch Drainage. For waterways on flat slopes of 0.5% or less grade, the use of a drainage ditch located along the center line of the waterway is effective in carrying the extended drainage flow estimated from the appropriate drainage curve. The waterway is designed large enough to carry estimated 10-year peak discharge rate. The drainage ditch prevents meander channels and maintains better velocity of the low flows of long duration.

Sloping of Overfalls in Grassed Waterways

Often an overfall exists in or at the end of a natural waterway where it enters a main channel. When such a condition occurs, a sloping vegetated channel can be constructed at the point of overfall if the drop is within the limits that will permit a safe slope to be established for a reasonable amount of excavation. Because of the steep grades that are encountered, the channel is required to carry water at a very low depth to keep the velocity within safe limits. It is not practical to construct vegetated channels on steep grades to widths greater than 30 to 40 feet because of

Transition from tile drain to open ditch using corrugated metal pipe to prevent displacement of the end joints of tile.



CORRUGATED METAL PIPE OUTLET ON DRAIN TILE

Fig. 5.16

3. DESIGN (CONT'D)

Sloping of Overfalls in Grassed Waterways (cont'd)

the problems involved in maintaining good flow distribution throughout the cross section. Waterways wider than 35 feet may be constructed with dividers which have about 0.4 feet effective height. In this way, a wide waterway is divided into multiple channels of equal width not greater than 35 feet. For larger drainage areas and adverse site conditions, grade control structures may need to be considered.

4. LAYOUT

Staking for Waterway Shaping

The width of the waterway is staked before construction to show the lateral limits of shaping. Staking length of the waterway is particularly important at the upper end to assure that shaping reaches far enough up the slope to receive outflow from all planned terraces or diversions. Staking the lower end of the waterway all the way down to a stable watercourse is important, also.

Adequate stakes will be set to define construction limits. Alignment should be adjusted to eliminate abrupt changes in width and sharp curves. The minimum radius of the inside curve of a waterway shall not be less than 50 feet.

5. CONSTRUCTION

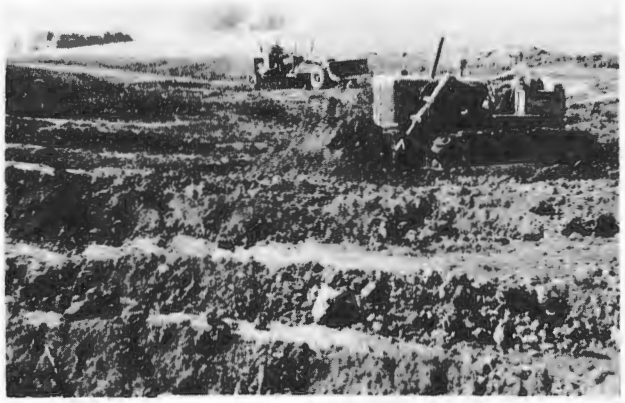
Waterway Shaping

With Farm Equipment. Many excellent waterways have been prepared using only a plow, disk and harrow. These tools work best when it is possible to drive a tractor anywhere over the waterway area without danger of overturning the tractor.

As the size of the waterway increases, the greater is the advantage of additional tools and equipment. A manure loader or similar tractor-mounted farm equipment may be used to advantage to slope steep banks by pushing in dirt from the top. When sloping is done from the top, care must be taken to secure compaction of the loose fill material. Not more than 8-12 inches of loose material should be allowed to accumulate before compaction is accomplished. Then sloping can be resumed and the process repeated until completed. It is desirable, also, to fill some low places and cut into banks and ridges to improve both grade and alignment; the Fresno or roll-over scraper and manure loader can be used to advantage.

With Heavy Grading Equipment. Motor graders can be used in working in and completing the grading. The highway auto patrol grader is excellent equipment for all kinds of waterway work. On large, deep, and irregular watercourses, the track tractor with bulldozer can be the most economical type of equipment. Construction methods are illustrated by Figures 5.17 through 5.22.

CONSTRUCTION OF VEGETATED OUTLETS AND WATERWAYS



MOTOR PATROL AND BULL DOZER SHAPING NATURAL WATER COURSE INTO WATERWAY

CLEARING TREES AND SHAPING PARABOLIC CROSS SECTION - DOZER AND PATROL

SHAPING GULLY ABOVE DROP INLET STRUCTURE WITH DOZER

SCRAPER AND DOZER SHAPING AND STRAIGHTENING WATERWAY

Fig. 5.17

CONSTRUCTION OF VEGETATED OUTLETS AND WATERWAYS

NEWLY BUILT WATERWAY WITH LEVEES TO PROTECT GRASS SEEDING TEMPORARILY

DOZER SHAPED WATERWAY LEADING TO COMPLETED GRADE STABILIZATION STRUCTURE

DOZER SHAPING A WATERWAY SEEDED 10 YEAR AGO WITHOUT BEING SHAPED

DEEP GULLY HAS BEEN SHAPED INTO A WATER-WAY AND SEEDED

Fig. 5.18

CONSTRUCTION OF VEGETATED OUTLETS AND WATERWAYS

GULLY BEFORE SHAPING DIVIDES THE FARM

WATERWAY AFTER SHAPING WITH DOZER AND PATROL READY FOR COVER CROP SEEDING

ESTABLISHED WATERWAY WITH DIVIDERS TO GIVE BETTER FLOW DISTRIBUTION

DEEP GULLY ABOVE GRADE CONTROL STRUCTURE BEING SHAPED WITH BULL DOZER

Fig. 5.19

CONSTRUCTION OF VEGETATED OUTLETS AND WATERWAYS

WASTELAND GULLY BEFORE WATERWAY SHAPING

COMPLETED WATERWAY AFTER SEEDING WILL PRODUCE HAY AND GRASS SEED

MOTOR PATROL MAKING FIRST ROUND IN SHAPING A WATERWAY

MOTOR PATROL MAKING FINAL ROUND IN SHAPING A WATERWAY

Fig. 5.20

CONSTRUCTION OF VEGETATED OUTLETS AND WATERWAYS

COMPLETED WATERWAY READY FOR MULCHING BEFORE SEEDING

SPREADING STRAW OR HAY MULCH WITH THE MANURE SPREADER

SINGLE DISC WEIGHTED FOR MULCH ANCHORING

PUNCHING HAY MULCH INTO SOIL AFTER SEEDING

Fig. 5.21

CONSTRUCTION OF VEGETATED OUTLETS AND WATERWAYS

DRILLING CORN FOR COVER CROP PREPARATORY TO SEEDING GRASSES

SPREADING STRAW MULCH ON THE NEWLY SEEDED GRASS WATERWAY

PACKING THE SEED BED AND MULCH ON NEWLY SEEDED GRASS WATERWAY

BUILDING A BERM TO PROTECT NEW GRASS SEEDING UNTIL SOD IS ESTABLISHED

Fig. 5.22

5. CONSTRUCTION (CONT'D)

Saving the Topsoil

In extreme cases of poor and infertile soil areas, it may be desirable first to remove the remaining topsoil and work it away from the waterway area, then grade in the watercourse, and later bring back the topsoil as a covering for the waterway. This is difficult and expensive but may be necessary to establish vegetation.

Establishing Vegetation

Success of a vegetated waterway will depend on obtaining physical conditions favorable to growth and maintenance of the vegetative cover. All agronomy practices that apply in establishing vegetation on a field need special emphasis when applied to the watercourse because the sod must withstand the additional hazard of flowing water. The determination of waterway dimensions based on proper design will reduce this hazard to an economical minimum.

Also of major importance for the successful establishment and maintenance of a vegetated waterway is the conservation treatment in the watershed. The better the erosion control effected in the watershed, the less the silting problem in the waterway. When a gully occurs in a waterway that is selected to serve as a part of the water disposal system, it is filled in by plowing or blading in the banks and moving enough earth to secure either a trapezoidal or parabolic cross section. All trash should be removed prior to filling operations. While the alignment of a natural waterway is governed by topography, sharp curves should be flattened. All fill material should be compacted as much as is practical with the equipment available to reduce erosion during the period of establishment of vegetation and provide a good seed bed.

The success of a vegetated waterway will depend on the proper shaping and preparation to produce conditions favorable to vegetative growth. Since vegetation is subject to deterioration through abuse and unfavorable seasons, it is necessary to provide maintenance, also. Between the time of seeding and actual establishment, a watercourse is unprotected and subject to considerable damage unless special protection is provided. Therefore, it is important to protect the waterway with temporary measures such as cover crops and levees to control runoff water.

The application of 2 to 3 tons per acre of mulch over the seeded waterway in the form of native hay, tame hay, or straw, is a good investment toward the establishment of a stand of grass. The mulch should be anchored against wind and water removal with a disk set straight, notched coulters, or other machines which tend to punch the mulch partially into the ground.

The advance growth of a cover crop, such as sudan grass or other sorghums, is excellent practice in preparation for seeding native grasses.

5. CONSTRUCTION (CONT'D)

Establishing Vegetation (cont'd)

Heavy applications of manure on waterway seedings help serve the purpose of mulch, provide needed organic matter for improved soil structure, and supplies needed plant food.

6. MAINTENANCE

Adequate maintenance of vegetated waterways may involve the following:

1. Damaged areas or trickle channels must be repaired promptly with added dirt, seed, sod, mulch, fertilizer, manure, etc.

2. Must be mowed once or twice a year at 4-6 inch height, using care not to expose young seedlings to intense heat and sunlight.

3. Fertility must be maintained with barnyard manure or nitrogen fertilizer.

4. Tillage operations must be performed at approximate right angles to waterways. Tillage tools should be lifted to avoid damage to waterways.

5. The waterway must not be used for a driveway, lane, or road.

6. Levees must be removed promptly when grass is well established, and the terrace water cut in.

7. EQUIPMENT

The important farm machinery needed to maintain and properly use vegetated waterways includes a mower and power lift tillage tools. A manure spreader, grass seeding equipment, and a mulch anchoring tool are very useful implements.

GPO 857257

CONTENTS

PART 6

DIVERSION DITCHES

Subject	Page
1. General	6-1
Definition	6-1
Purpose	6-1
Applicable State Laws	6-1
2. Planning	6-1
Location	6-1
Velocity Limitations	6-1
Capacity	6-2
3. Construction	6-2
4. Maintenance	6-2
5. Dimensions	6-3

LIST OF FIGURES

PART 6

DIVERSION DITCHES

Figure Number	Title	Page
	Diversion Ditch Capacities:	
	"C" Retardance	
6.1	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 2:1	6-4
6.2	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 2:1	6-5
6.3	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 3:1	6-6
6.4	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 3:1	6-7
6.5	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 4:1	6-8
6.6	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 4:1	6-9
6.7	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 6:1	6-10
6.8	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 6:1	6-11
	"D" Retardance	
6.9	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 2:1	6-12
6.10	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 2:1	6-13
6.11	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 3:1	6-14
6.12	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 3:1	6-15
6.13	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 4:1	6-16
6.14	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 4:1	6-17
6.15	Channel Grades 0.1, 0.2, 0.3 and 0.4 - Side Slopes 6:1	6-18
6.16	Channel Grades 0.5, 0.6, 0.8 and 1.0 - Side Slopes 6:1	6-19
6.17	Hydraulic Radius for Out of Channel Flows	6-20
6.17.1	Hydraulic Radius for Out of Channel Flows	6-20.1
6.18	Cross-Sectional Area and Velocity for Out of Channel Flows	6-21
6.19	Diversion Ditch Located Above Irrigated Field (Corn) to Protect It From Surface Runoff	6-22
6.20	Sketch Showing Typical Diversion Ditch to Protect Cultivated Field Runoff From Pasture Land Above	6-22

PART 6

DIVERSION DITCHES

1. GENERAL

Definition

A diversion ditch is a channel on a predetermined grade with supporting ridge on the lower side, constructed for the purpose of intercepting runoff and conducting it at a safe velocity to a protected outlet or water-spreading area.

Purpose

Purposes of diversions may include but are not limited to the following:

(1) To minimize erosion and protect cropland from the runoff of adjoining land.

(2) To divert water into a pond or grade stabilization structure.

(3) To divert water away from the head of an active gully or roadside ditch.

(4) To divert water to an area where it can be spread to increase the vegetation.

Applicable State Laws

Consideration must be given to state laws which govern the diversion of water when planning, designing, or installing diversion ditches.

2. PLANNING

Location

Diversions must be located where they will perform the desired function. The upper end of the diversion must intercept the flow of water at the desired location and the lower end must discharge in a channel or area that is capable of carrying the additional water without erosion. Susceptibility to sedimentation from above must be considered, also. The greatest cause of failure of diversions is sediment washing into the channel of the diversion. Velocities in diversion ditches usually should be as high as can be safely allowed.

Velocity Limitations

Relatively high velocities maintain the capacity of the channel and reduce the danger of obstruction from sedimentation. Too high velocities will cause erosion. Ordinarily safe velocities are as follows:

2. PLANNING (CONT'D)

Velocity Limitations (cont'd)

Bare channels after aging	
Non-colloidal sandy or silt loam	1.5 - 3.0 fps
Ordinary loam	2.5 - 3.5 fps
Colloidal clay	3.0 - 5.0 fps
Fine gravel	2.5 - 5.0 fps
Coarse gravel	4.0 - 6.0 fps
Cobbles, shales, and hardpans	5.0 - 6.5 fps
Poor channel vegetation	2.5 - 3.5 fps
Fair channel vegetation	3.5 - 4.5 fps
Good channel vegetation	4.5 - 5.0 fps

In general, waters carrying colloidal silts are a little less erosive than clear waters or waters carrying non-colloidal silts or gravel.

Capacity

The size of the diversion channel is determined primarily by the estimated peak flow from the drainage being diverted. Capacities of diversion channels may be computed by Manning's Formula or taken from hydraulic or design tables. Expected peak flows are computed as shown in Part 3 of this handbook. The peak flow for determining capacity shall be equal to or greater than that for a ten-year frequency storm. Channel width, depth, grade, and resulting velocities are determined for peak flows from the charts in Figures 6.1 through 6.18; these capacities are based on Manning's Formula. On long diversions, the size is often designed by reaches and the diversion dimensions are based upon the expected peak flow from the drainage into each reach.

3. CONSTRUCTION

Power equipment such as road patrols, graders, dozers and terracers usually are used in building diversions. Care must be taken to build the diversion exactly as planned since failure to do so will result in changes in capacity and possible over-topping of the diversion. Diversions for water-spreading on range land often are constructed with the excavated earth placed on the downhill side of the channel where it intercepts and on the uphill side of the channel in the spreading area.

4. MAINTENANCE

The most difficult problem in maintaining diversions is usually that of removal of silt. Excessive channel silting generally indicates inadequate vegetative cover on the watershed. Rodent holes and breaks should be repaired promptly.

5. DIMENSIONS

Capacity

Determine the capacity by use of figures on pages 6.4 to 6.21.

The following figures are based on SCS-TP-61 - Retardance "C" and "D":

(1) Channel Grades - 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.8 and 1.0%.

(2) Side Slopes - 2:1, 3:1, 4:1, and 6:1.

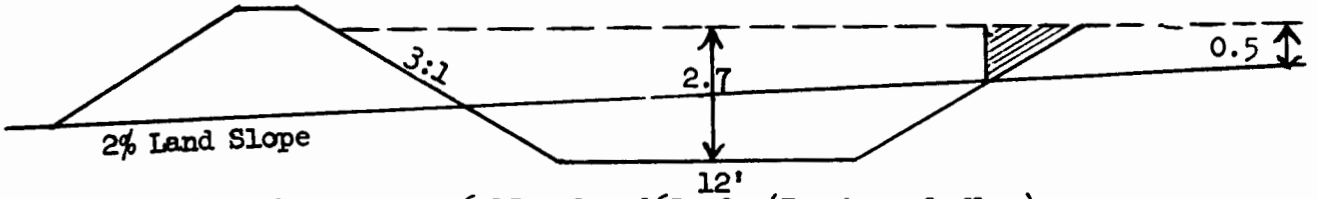
(3) Bottom Widths - 4, 6, 8, 10, 12, 14, 16 and 18 feet.

Example for use of figures:

Determine the capacity of a diversion having the following dimensions and built on a two percent land slope. Vegetation in the channel will be maintained at a "D" retardance condition.

(1) Bottom width - 12 feet
(2) Side slopes - 3:1
(3) Diversion Grade - 0.5' per 100'
(4) Depth of flow - 2.7 feet

Diversion to be constructed as a balanced cut-fill section with cut-fill ratio 1.25:1.00.



From figure page 6-15: Q = 265 cfs (In channel flow)
From figure page 6-20.1: "R" for out of channel flow = .76.

Then from figure page 6-21 for "R" of .76,
Cross section area = 19.8, and Velocity = 1.6.

Therefore, Q = 1.6 x 19.8 or Q = 31.7 - Out of channel flow
Total Capacity = 265 + 32 = 297 cfs.

The out of channel flow is calculated to a point where depth of flow equals 0.5 ft. Velocity for depths less than this become so low that the capacity is negligible. It is recognized that technically the hydraulic radius of the channel would be calculated to the point where the cut leaves the ground line. However this small triangle has very little affect on the average velocity of the entire channel. The above procedure allows for a double calculation of the small shaded triangle and this compensates for the slight increase of velocity within this area. The procedure above gives as near an exact capacity as can be obtained through any method of calculation.

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"C" Retardance

Side Slope = 2:1

Channel Grade - 0.1% — Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
								1.1
						6	7	1.3
		4	6	8	11	13	15	1.5
	5	8	12	16	19	22	26	1.7
6	11	15	20	25	30	34	39	1.9
9	15	22	28	35	41	47	54	2.1
14	22	30	38	46	54	63	71	2.3
19	29	39	49	59	70	80	90	2.5
25	37	50	62	74	86	99	110	2.7
32	46	61	75	90	104	118	133	2.9
39	56	72	89	106	123	139	156	3.1

(0.5) (1.0) (1.5) (2.0)

Channel Grade - 0.2% — Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
10	9	7	6	4	3			1.1
20	17	15	12	10	7	4	2	1.3
36	32	27	23	18	14	9	5	1.5
55	48	42	35	29	22	16	9	1.7
77	68	59	50	41	32	23	14	1.9
101	90	78	67	55	44	32	21	2.1
127	113	99	85	71	57	43	29	2.3
155	138	122	105	88	71	55	38	2.5
185	166	146	127	107	88	68	49	2.7
217	195	172	150	128	106	83	61	2.9
250	225	200	174	149	124	99	74	3.1

(0.5) (1.0) (1.5) (2.0)

Channel Grade - 0.3% — Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
2	4	7	9	12	14	16	19	1.1
4	8	12	16	20	25	29	33	1.3
9	15	22	28	35	41	48	54	1.5
15	24	33	42	51	60	69	78	1.7
22	34	46	56	69	81	93	105	1.9
31	46	60	75	90	104	119	134	2.1
41	59	76	94	112	130	147	165	2.3
52	73	94	114	135	156	177	198	2.5
65	89	113	137	162	186	210	234	2.7
80	107	135	162	190	217	244	272	2.9
95	126	157	188	219	250	280	311	3.1

(0.5) (1.0) (2.0) (3.0) (4.0)

Channel Grade - 0.4% — Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
28	24	21	17	14	10	6	3	1.1
46	40	35	29	24	18	12	7	1.3
71	63	54	46	38	30	21	13	1.5
99	88	77	66	54	43	32	21	1.7
130	116	101	87	73	58	44	30	1.9
164	146	128	111	93	75	58	40	2.1
200	179	158	136	115	94	73	52	2.3
239	214	190	165	140	115	91	66	2.5
280	252	223	195	166	138	109	81	2.7
324	292	259	227	194	162	129	97	2.9
370	334	297	261	224	188	151	115	3.1

(1.0) (2.0) (3.0) (4.0) (5.0)

Figure 6.1 -- Velocity in ft. per sec. shown as follows: ⌐└ ( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"C" Retardance

Side Slope = 2:1

Channel Grade - 0.5% — Bottom Width in Feet								Flow Depth	Channel Grade - 0.6% — Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
5	9	14	18	23	27	32	36	1.1	43	38	33	28	22	17	12	7
10	17	24	31	38	45	52	59	1.3	70	62	54	46	37	29	21	13
17	27	37	47	57	67	77	87	1.5	101	90	78	67	55	44	32	21
26	39	52	66	79	92	106	119	1.7	136	121	106	91	76	61	46	31
36	53	70	86	103	120	137	154	1.9	175	156	137	118	100	81	62	43
48	68	89	110	130	151	171	192	2.1	217	194	171	148	125	102	79	56
62	86	111	135	160	184	208	233	2.3	262	235	208	180	153	126	99	72
78	106	135	163	192	220	248	277	2.5	309	278	246	215	183	152	120	89
95	128	160	193	226	259	291	324	2.7	360		288	252	216	180	144	108
114	151	188	225	263	300	337	374	2.9	414		333	292	251	210	169	128
134	176	218	260	302	344		426	3.1	471				287	241	195	149

(1.0) (2.0) (3.0) (4.0) (5.0) — (1.0) (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8% — Bottom Width in Feet								Flow Depth	Channel Grade - 1.0% — Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
10	17	23	30	37	44	50	57	1.1	70	62	54	46	37	29	21	13
18	28	38	49	59	69	80	90	1.3	106	94	82	70	58	46	34	22
28	42	56	70	84	99	113	127	1.5	147	131	115	98	82	66	50	34
40	58	76	95	113	131	150	168	1.7	193	172	152	131	110	89	69	48
54	77	99	122	144	167	189	212	1.9	244	218	193	167	142	116	90	64
70	97	124	151	179	206	233	260	2.1	300			206	175	144	113	82
89	121	153	185	216	249		312	2.3	360						139	103
109	146	183					368	2.5								
131	173						428	2.7								
								2.9								
								3.1								

(2.0) (3.0) (4.0) (5.0) — (2.0) (3.0) (4.0) (5.0)

Figure 6.2 -- Velocity in ft. per sec. shown as follows: ⌐└___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES
"C" Retardance
Side Slope = 3:1

Channel Grade - 0.1% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
							7	1.3
			5	8	10	12	15	1.5
	5	8	12	16	19	22	26	1.7
6	11	15	20	25	30	34	39	1.9
10	16	22	29	35	41	48	54	2.1
15	23	31	39	48	56	64	72	2.3
22	32	42	52	62	72	82	92	2.5
30	42	54	66	78	90	102	114	2.7
39	53	67	81	95	110	124	138	2.9
49	65	82	98	115	131	147	164	3.1

(0.5) (1.0) (1.5)

Channel Grade - 0.2% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
10	8	6	5	3				1.1
20	17	15	12	10	7	4	2	1.3
36	32	27	23	18	14	9	5	1.5
55	48	42	35	29	22	16	9	1.7
77	68	60	51	42	33	25	16	1.9
102	91	80	69	57	46	35	24	2.1
130	116	103	89	75	61	48	34	2.3
160	144	127	111	95	79	62	46	2.5
194	175	156	137	118	99	80	61	2.7
230	208	186	164	142	120	98	76	2.9
268	243	218	193	169	144	119	94	3.1

(0.5) (1.0) (2.0) (3.0)

Channel Grade - 0.3% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
	2	5	8	10	13	16	19	1.1
4	8	12	16	20	25	29	33	1.3
10	16	22	29	35	41	48	54	1.5
17	26	35	44	52	61	70	79	1.7
25	37	48	60	71	83	94	106	1.9
36	50	65	79	94	108	123	137	2.1
49	66	84	101	119	136	154	171	2.3
64	84	105	125	146	166	187	207	2.5
81	105	128	152	176	200	223	247	2.7
100	127	154	181	209	236	263	290	2.9
121	152	182	213	243	274	304	335	3.1

(0.5) (1.0) (2.0) (3.0)

Channel Grade - 0.4% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
28	24	21	17	14	10	6	3	1.1
46	40	35	29	24	18	12	7	1.3
71	64	55	47	39	30	22	14	1.5
100	90	79	68	56	45	34	23	1.7
132	118	104	90	76	62	48	34	1.9
169	152	134	117	99	82	64	47	2.1
209	188	167	146	126	105	84	63	2.3
252	227	203	178	154	129	105	80	2.5
298	261	234	207	181	154	127	101	2.7
347	315	283	251	219	187	155	123	2.9
399	363	327	291	255	219	188	147	3.1

(0.5) (1.0) (2.0) (3.0) (4.0)

Figure 6.3 -- Velocity in ft. per sec. shown as follows: ⌐└___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"C" Retardance

Side Slope = 3:1

Channel Grade - 0.5% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
5	9	14	18	23	27	32	36	1.1
10	17	24	31	38	45	52	59	1.3
19	29	38	48	58	68	77	87	1.5
29	42	56	69	82	95	109	120	1.7
42	59	75	92	109	126	142	158	1.9
57	77	98	118	139	159	180	199	2.1
75	99	124	148	173	197	222	244	2.3
95	124	152	181	210	238	267	293	2.5
118	151	183	216	248	281	314	346	2.7
144	180	216	253	289	325	362	402	2.9
172	212	252	293	333	373	414	463	3.1

(1.0) (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.6% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
43	38	33	28	22	17	12	7	1.1
70	62	54	46	37	29	21	13	1.3
101	90	79	68	56	45	34	23	1.5
138	123	108	94	79	64	50	35	1.7
180	161	143	124	106	87	68	50	1.9
226	203	180	158	135	112	90	67	2.1
275	249	222	195	168	141	114	87	2.3
328	298	267	236	204	173	141	110	2.5
385	347	311	276	241	306	170	135	2.7
		362	322	282	242	202	163	2.9
				326	282	237	193	3.1

(1.0) (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
10	17	23	30	37	44	50	57	1.1
19	29	39	49	60	70	80	90	1.3
31	45	59	73	87	101	115	129	1.5
46	64	82	100	118	136	154	172	1.7
63	85	108	130	153	175	198	220	1.9
84	111	139	166	194	221	248	272	2.1
108	140	173	205	238	270	302	329	2.3
134	172	210	248					2.5
164	206							2.7
								2.9
								3.1

(2.0) (3.0) (4.0) (5.0)

Channel Grade - 1.0% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
70	62	54	46	37	29	21	13	1.1
107	95	83	71	60	48	36	24	1.3
150	134	118	102	86	70	54	38	1.5
199	178	158	137	117	96	76	55	1.7
254	230	204	178	152	127	101	75	1.9
314	281	251	220	190	159	128	98	2.1
					196	160	124	2.3
						197	156	2.5
								2.7
								2.9
								3.1

(2.0) (3.0) (4.0) (5.0)

Figure 6.4 -- Velocity in ft. per sec. shown as follows: ⌐└( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"C" Retardance

Side Slope = 4:1

Channel Grade - 0.1% Bottom Width in Feet								Flow Depth	Channel Grade - 0.2% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
								1.1	10	8	6	4				
							7	1.3	21	18	16	13	10	7	5	2
						10	16	1.5	36	32	27	23	18	14	9	5
		7	11	15	19	23	27	1.7	55	48	42	36	29	23	16	10
6	11	16	20	25	30	35	40	1.9	78	69	60	52	43	34	26	17
11	17	24	30	36	42	49	55	2.1	104	93	82	71	60	49	38	27
17	25	33	41	49	57	65	73	2.3	133	120	107	93	80	67	53	40
26	36	45	55	65	74	84	94	2.5	166	150	134	118	102	86	70	54
36	48	59	71	83	94	106	118	2.7	203	184	166	147	128	109	91	72
47	61	75	89	102	116	130	144	2.9	243	221	200	178	156	134	113	91
60	76	92	108	124	141	157	173	3.1	286	261	237	213	188	163	139	114

(0.5) (1.0) (0.5) (1.0) (2.0) (3.0)

Channel Grade - 0.3% Bottom Width in Feet								Flow Depth	Channel Grade - 0.4% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
	2	5	8	10	13	16	19	1.1	28	24	21	17	14	10	6	3
5	9	13	17	22	26	30	34	1.3	47	41	36	30	25	19	14	8
10	16	23	29	36	42	49	55	1.5	72	64	56	48	39	31	23	15
18	27	36	45	53	62	71	80	1.7	101	90	79	68	58	47	36	25
28	39	51	62	74	85	97	108	1.9	135	121	107	93	80	66	52	38
41	55	70	84	98	113	127	141	2.1	175	158	140	123	106	88	71	54
56	73	91	108	125	143	160	177	2.3	217	196	176	155	135	114	94	73
75	95	116	136	156	177	197	217	2.5	265	241	217	192	169	144	119	95
96	120	143	167	190	214	238	261	2.7	316	288	260	232	204	176	148	120
121	148	175	202	228	255	282	309	2.9	371	339	307	275	244	212	180	148
148	178	208	238	268	299	329	359	3.1	429	393	358	322	286	250	215	179

(0.5) (1.0) (2.0) (3.0) (0.5) (1.0) (2.0) (3.0) (4.0)

Figure 6.5 -- Velocity in ft. per sec. shown as follows: ⌐ ( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"C" Retardance

Side Slope = 4:1

Channel Grade - 0.5% — Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
5	9	14	18	23	27	32	36	1.1
11	18	25	32	38	45	52	59	1.3
20	30	39	49	59	69	78	88	1.5
32	45	58	70	83	96	109	122	1.7
48	64	81	97	113	130	146	162	1.9
66	86	106	126	146	166	186	206	2.1
88	112	136	160	183	207	231	255	2.3
113	141	169	197	225	253	281	309	2.5
142	174	206	238	271	303	335	367	2.7
174	211	247	284	320	357	393	430	2.9
209	250	292	333	375	416	458	499	3.1

(1.0) (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.6% — Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
43	39	33	28	22	17	12	7	1.1
70	62	54	46	38	30	22	14	1.3
102	91	80	69	58	47	36	25	1.5
141	126	112	97	83	68	54	39	1.7
186	168	149	131	112	94	75	57	1.9
235	213	190	168	145	123	100	78	2.1
290	263	236	209	183	155	129	102	2.3
349	318	287	255	224	193	161	130	2.5
412	376	341	305	269	233	198	162	2.7
480	440	399	359	319	279	238	198	2.9
			417	372	328	283	238	3.1

(1.0) (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8% — Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
10	17	23	30	37	44	50	57	1.1
20	30	40	50	61	71	81	91	1.3
34	48	61	75	89	103	116	130	1.5
52	70	87	105	123	141	158	176	1.7
73	95	117	139	161	183	205	227	1.9
98	125	151	178	204	231	257	284	2.1
127	158	190	221	253	284	316	347	2.3
160	197	233	270	306	343	379		2.5
197	239	281	323					2.7
								2.9
								3.1

(2.0) (3.0) (4.0) (5.0)

Channel Grade - 1.0% — Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
70	62	54	46	38	30	22	14	1.1
108	96	85	73	61	49	38	26	1.3
153	137	122	106	90	74	59	43	1.5
204	184	164	144	123	103	83	63	1.7
263	238	212	187	162	137	111	86	1.9
328	297	267	236	206	175	145	114	2.1
			292	255	219	183	147	2.3
						228	186	2.5
								2.7
								2.9
								3.1

(2.0) (3.0) (4.0) (5.0)

Figure 6.6 -- Velocity in ft. per sec. shown as follows: ⌐└___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"C" Retardance

Side Slope = 6:1

Channel Grade - 0.1% Bottom Width in Feet								Flow Depth	Channel Grade - 0.2% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
							7	1.1	10	7	4					
						9	16	1.3	21	18	16	13	10	7	5	2
			9	14	18	22	27	1.5	36	32	27	23	19	14	10	6
	10	15	20	25	30	35	40	1.7	55	47	42	36	30	24	17	11
13	19	25	31	38	44	50	56	1.9	79	71	62	54	45	37	28	20
22	30	37	45	52	60	67	75	2.1	107	96	86	75	65	54	44	33
33	42	52	61	70	79	89	98	2.3	140	127	114	101	88	76	63	50
47	58	69	80	92	103	114	125	2.5	178	162	147	132	116	101	85	70
63	76	90	103	116	129	143	156	2.7	221	203	185	166	148	130	112	94
81	97	112	128	144	160	175	191	2.9	269	248	227	206	185	164	143	122
								3.1	321	297	273	249	226	202	178	154

(0.5) (1.0) (0.5) (1.0) (2.0)

Channel Grade - 0.3% Bottom Width in Feet								Flow Depth	Channel Grade - 0.4% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
			5	8	12	16	19	1.1	28	24	21	17	14	10	6	3
5	9	13	17	22	26	30	34	1.3	47	41	36	30	25	19	14	8
11	17	24	30	36	42	49	55	1.5	72	64	56	48	40	33	25	17
21	30	38	47	55	64	72	81	1.7	103	92	82	72	61	51	40	30
34	45	56	67	78	89	100	111	1.9	141	127	114	101	87	74	60	47
51	65	79	92	106	120	134	148	2.1	185	168	152	135	119	102	86	69
72	89	106	122	139	156	173	190	2.3	235	215	195	175	155	135	115	95
98	118	138	158	177	197	217	237	2.5	291	267	244	220	196	172	149	125
128	151	174	197	220	243	266	289	2.7	352	325	297	269	242	214	187	159
162	188	214	241	267	293	320	346	2.9	418	386	355	324	292	261	229	198
200	230	259	289	319	349	378	408	3.1	489	454	419	383	348	313	277	242

(0.5) (1.0) (2.0) (3.0) (1.0) (2.0) (3.0) (4.0)

Figure 6.7 -- Velocity in ft. per sec. shown as follows: (4.0) ( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"C" Retardance

Side Slope = 6:1

Channel Grade - 0.5% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
5	9	14	18	23	27	32	36	1.1
12	19	25	32	39	46	52	59	1.3
23	32	42	51	61	70	80	89	1.5
39	51	64	76	89	101	114	126	1.7
59	75	91	106	122	138	154	170	1.9
84	104	123	143	162	182	201	221	2.1
114	137	161	184	208	231	254	278	2.3
149	176	204	231	259	286	314	341	2.5
189	221	252	284	315	347	378	410	2.7
234	270	306	342	377	413	449	485	2.9
284	324	365						3.1

(1.0) (2.0) (3.0) (4.0)

Channel Grade - 0.6% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
43	38	33	28	22	17	12	7	1.1
70	62	54	46	38	31	23	15	1.3
104	93	82	72	61	50	40	29	1.5
146	132	118	104	90	76	62	48	1.7
196	178	160	142	124	107	89	71	1.9
253	231	209	187	165	143	121	99	2.1
317	290	264	238	211	185	158	132	2.3
387	356	325	294	264	233	202	171	2.5
463	428	392	357	321	286	250	215	2.7
546	506	466	426	385	345	305	265	2.9
635	590	545	500	456	411	366	321	3.1

(1.0) (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
10	17	23	30	37	44	50	57	1.1
23	33	42	52	62	72	81	91	1.3
41	54	67	80	94	107	120	133	1.5
64	81	98	115	132	149	166	183	1.7
92	113	134	156	177	198	220	241	1.9
125	151	177	203	229	255	281	307	2.1
164	195	226	257	288	319	350	381	2.3
209	245	281	317	353	390	426	462	2.5
260	302	343	385	426	468			2.7
317								2.9
								3.1

(1.0) (2.0) (3.0) (4.0) (5.0)

Channel Grade - 1.0% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
70	62	54	46	38	30	22	14	1.1
110	98	87	76	64	53	41	30	1.3
158	143	127	112	97	82	66	51	1.5
215	195	176	156	136	116	97	77	1.7
280	255	231	206	182	157	133	108	1.9
354	324	295	265	236	206	176	146	2.1
437	402	367	332	297	262	227	192	2.3
				365	325	286	247	2.5
								2.7
								2.9
								3.1

(2.0) (3.0) (4.0) (5.0)

Figure 6.8 -- Velocity in ft. per sec. shown as follows: ⌐└___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"D" Retardance

Side Slope = 2:1

Channel Grade - 0.1% Bottom Width in Feet								Flow Depth	Channel Grade - 0.2% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
	4	6	7	9	11	12	14	1.1	26	23	20	17	14	11	8	5
4	7	9	12	14	17	19	22	1.3	40	36	31	27	22	17	13	8
7	10	14	18	22	26	29	33	1.5	57	50	44	38	31	25	19	13
10	15	20	25	30	35	40	46	1.7	76	67	59	51	42	34	26	19
14	21	27	34	40	47	53	60	1.9	97	86	76	66	56	45	35	25
19	27	35	43	51	59	67	75	2.1	120	107	95	82	70	57	44	32
25	34	44	53	63	73	83	92	2.3	146	131	116	100	85	70	55	40
31	42	53	65	76	88	100	111	2.5	174	156	138	120	103	85	67	49
38	51	64	78	91	105	118	132	2.7	204	183	163	142	122	101	81	60
45	61	76	92	107	123	138	154	2.9	236	213	189	166	143	119	96	72
52	70	88	106	124	142	160	178	3.1	271	244	218	191	165	138	112	86

(0.5) (1.0) (1.5) (2.0) (1.0) (2.0) (3.0)

Channel Grade - 0.3% Bottom Width in Feet								Flow Depth	Channel Grade - 0.4% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
7	11	15	19	24	28	32	36	1.1	45	40	35	29	24	19	14	9
12	18	24	30	36	42	48	54	1.3	66	58	51	44	36	29	22	15
17	26	34	42	50	58	66	74	1.5	90	80	70	60	51	41	31	22
24	35	45	56	66	76	87	97	1.7	117	104	92	79	67	54	42	30
32	45	58	71	84	97	110	123	1.9	146	131	116	100	85	70	54	39
41	57	73	88	104	120	135	151	2.1	179	161	142	124	105	87	68	50
52	71	89	108	126	145	163	182	2.3	215	193	171	150	128	106	84	62
64	85	107	128	150	172	193	215	2.5	254	229	203	178	152	127	102	76
77	102	126	151	176	201	226	251	2.7	296	267	237	208	179	150	120	91
91	119	148	176	205	233	261	290	2.9	341	308	275	241	208	175	141	108
107	139	171	203	235	267	299	331	3.1	389	351	314	276	239	201	164	126

(1.0) (2.0) (3.0) (5.0) (2.0) (3.0) (4.0)

Figure 6.9 -- Velocity in ft. per sec. shown as follows: ⌐¬ ( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"D" Retardance

Side Slope = 2:1

Channel Grade - 0.5% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
11	17	23	29	35	41	47	53	1.1
18	26	35	43	52	60	69	77	1.3
26	37	48	59	71	82	93	105	1.5
35	49	64	78	93	107	121	136	1.7
46	64	82	99	117	135	152	170	1.9
59	80	101	122	144	165	186	207	2.1
73	98	123	148	173	198	223	248	2.3
89	118	147	176	205	234	263	292	2.5
106	139	173	206	240	273	307	340	2.7
125	163	201	239	277	315			2.9
146	188	231	274					3.1

(2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.6% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
61	54	47	40	34	27	20	13	1.1
88	78	68	59	49	39	30	20	1.3
118	105	92	80	67	54	42	29	1.5
152	136	120	104	88	72	56	39	1.7
190	171	151	131	111	91	72	51	1.9
232	209	185	161	137	114	90	65	2.1
278	251	223	194	166	138	110	81	2.3
	296	264	231	198	165	132	99	2.5
				232	194	157	118	2.7
						183	139	2.9
							162	3.1

(2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
17	25	33	41	50	58	66	74	1.1
25	37	48	60	71	83	95	106	1.3
35	51	66	81	97	112	127	143	1.5
48	67	87	106	126	145	164	184	1.7
63	87	110	134	158	182	205	239	1.9
80	108	137	165	193	222	250	278	2.1
99	133	167						2.3
120								2.5
								2.7
								2.9
								3.1

(3.0) (4.0) (5.0)

Channel Grade - 1.0% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
86	76	67	58	48	39	29	20	1.1
121	108	95	81	68	55	42	29	1.3
162	145	128	110	93	76	58	41	1.5
208	187	165	143	121	99	77	55	1.7
		206	179	152	125	98	71	1.9
							89	2.1
								2.3
								2.5
								2.7
								2.9
								3.1

(3.0) (4.0) (5.0)

Figure 6.10 -- Velocity in ft. per sec. shown as follows: ⌐└___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"D" Retardance

Side Slope = 3:1

Channel Grade - 0.1% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
2	4	5	7	9	10	12	14	1.1
4	7	10	12	15	17	20	22	1.3
7	11	15	18	22	26	29	33	1.5
11	16	21	26	30	35	40	45	1.7
16	23	29	35	42	48	54	60	1.9
22	30	38	46	54	62	70	77	2.1
29	39	48	58	67	77	87	96	2.3
37	48	60	71	83	94	105	117	2.5
46	59	73	86	100	113	126	139	2.7
56	71	87	102	118	133	148	165	2.9
67	85	102	120	138	155	173	191	3.1

(0.5) (1.0) (1.5) (2.0)

Channel Grade - 0.2% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
26	23	20	17	14	11	8	5	1.1
40	36	31	27	22	18	14	9	1.3
57	51	45	39	33	26	20	14	1.5
77	69	61	53	45	37	28	20	1.7
100	89	79	69	59	49	39	28	1.9
125	112	100	88	75	63	50	38	2.1
153	138	123	108	93	79	64	49	2.3
183	166	148	131	113	96	78	61	2.5
217	196	176	156	136	116	96	75	2.7
253	230	207	184	161	138	114	91	2.9
292	266	240	213	187	161	135	109	3.1

(1.0) (2.0) (3.0)

Channel Grade - 0.3% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
8	12	16	20	24	28	32	36	1.1
13	19	25	31	37	42	48	54	1.3
20	27	36	44	52	60	68	76	1.5
28	38	49	59	69	80	90	100	1.7
38	51	64	76	89	102	115	128	1.9
50	65	81	96	112	127	143	158	2.1
63	82	100	118	137	155	173	192	2.3
78	100	121	143	164	186	208	228	2.5
95	120	145	170	194	219	244	268	2.7
114	143	171	199	227	255	283	311	2.9
135	168	200	231	263	294	326	358	3.1

(1.0) (2.0) (3.0) (4.0)

Channel Grade - 0.4% Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
45	40	35	30	25	20	15	10	1.1
67	60	52	45	38	31	24	16	1.3
92	82	73	63	53	44	34	24	1.5
120	108	96	83	71	59	47	34	1.7
152	137	122	107	92	77	62	46	1.9
188	171	152	134	115	97	79	60	2.1
228	206	184	163	141	119	98	76	2.3
271	245	220	195	170	145	119	94	2.5
317	288	259	230	201	172	143	114	2.7
367	334	302	269	236	203	170	137	2.9
422	385	348	310	273	236	199	162	3.1

(2.0) (3.0) (4.0) (5.0)

Figure 6.11 -- Velocity in ft. per sec. shown as follows: ⌐_( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"D" Retardance

Side Slope = 3:1

Channel Grade - 0.5%								Flow Depth	Channel Grade - 0.6%							
Bottom Width in Feet									Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
12	18	24	30	36	41	47	53	1.1	61	54	48	41	34	28	21	14
20	28	36	45	53	62	70	78	1.3	89	80	70	61	51	42	32	22
29	40	52	63	74	85	96	107	1.5	121	108	96	83	71	58	46	33
41	55	69	83	98	112	126	140	1.7	157	142	126	110	94	78	62	46
55	72	90	107	125	142	159	177	1.9	198	179	160	140	120	101	81	62
71	91	112	133	154	175	196	217	2.1	244	221	197	174	150	127	103	80
89	114	139	163	188	213	238	262	2.3	295	266	239	211	183	155	128	100
110	138	167	196	225	254	282	311	2.5	350	317	285	253	220	188	155	123
133	166	199	232	265	298	331	364	2.7			335	298	261	223	186	148
158	195	233	270	308	346	383	421	2.9						263	220	176
185	227	270	312	354	397			3.1								207

(2.0) (3.0) (4.0) (5.0) — (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8%								Flow Depth	Channel Grade - 1.0%							
Bottom Width in Feet									Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
18	26	34	42	51	59	67	75	1.1	87	78	68	59	50	40	31	22
28	39	51	62	74	85	96	108	1.3	124	111	98	85	72	59	46	33
41	56	71	86	101	116	131	146	1.5	167	150	133	116	99	82	65	48
56	75	94	113	132	152	171	190	1.7	216	195	173	151	130	108	87	65
74	97	121	144	168	191	214	238	1.9	270	243	217	191	164	138	111	85
95	123	151	179	207	235	263	291	2.1						172	140	108
120	153	185	218					2.3								134
149								2.5								
								2.7								
								2.9								
								3.1								

(3.0) (4.0) (5.0) — (3.0) (4.0) (5.0)

Figure 6.12 -- Velocity in ft. per sec. shown as follows: ⌐└___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"D" Retardance

Side Slope = 4:1

Channel Grade - 0.1% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
	2	4	6	8	10	12	14	1.1
5	7	10	12	15	17	20	22	1.3
(0.5) 8	12	15	19	22	26	30	33	1.5
12	17	22	27	32	37	42	46	1.7
18	25	31	37	43	50	56	62	1.9
(1.0) 25	33	41	49	57	64	72	80	2.1
34	44	53	62	72	81	90	100	2.3
44	55	66	77	89	100	111	122	2.5
55	68	81	94	108	121	134	147	2.7
68	83	98	113	128	144	159	174	2.9
(1.5) 82	99	116	134	151	169	186	204	3.1
				(2.0)				

Channel Grade - 0.2% Bottom Width in Feet								
18	16	14	12	10	8	6	4	
26	23	20	17	14	12	9	6	1.1
40	36	32	27	23	19	14	10	1.3
58	52	46	40	34	28	22	16 (1.0)	1.5
79	71	63	55	47	39	31	24	1.7
103	93	83	73	63	53	43	34	1.9
130	117	105	93	81	69	57	45	2.1
160	145	131	116	102	87	72	58	2.3
193	176	158	141	124	107	90	73 (2.0)	2.5
230	210	190	170	150	130	110	90	2.7
270	247	224	201	179	156	133	110	2.9
313	287	261	235	209	184	158	132	3.1
				(3.0)				

Channel Grade - 0.3% Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
8	12	16	20	24	28	32	36	1.1
(1.0) 14	20	26	32	37	43	49	55	1.3
22	30	38	46	54	62	70	77	1.5
32	42	52	62	73	83	93	103	1.7
44	56	69	82	95	107	120	133	1.9
(2.0) 58	73	89	104	119	135	150	166	2.1
74	93	111	129	147	166	184	202	2.3
93	114	136	157	178	199	220	242	2.5
115	139	164	188	212	237	261	285	2.7
(3.0) 139	166	194	222	250	277	305	332	2.9
166	197	228	259	290	321	352	383	3.1
							(4.0)	

Channel Grade - 0.4% Bottom Width in Feet								
18	16	14	12	10	8	6	4	
45	40	35	30	25	20	16	11	1.1
68	61	54	46	39	32	25	18	1.3
94	84	75	65	56	46	37	27	1.5
124	111	98	86	73	60	47	39 (2.0)	1.7
158	143	128	114	98	84	69	53	1.9
197	180	161	143	125	107	89	70	2.1
240	218	197	176	154	133	111	90 (3.0)	2.3
287	262	237	212	187	162	137	112	2.5
338	310	281	252	223	195	166	137	2.7
394	361	328	296	263	230	198	165	2.9
454	417	380	344	307	270	233	196	3.1
						(4.0)		

Figure 6.13 -- Velocity in ft. per sec. shown as follows: ⌐⌊____( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"D" Retardance

Side Slope = 4:1

Channel Grade - 0.5% — Bottom Width in Feet								Flow Depth	Channel Grade - 0.6% — Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
13	19	25	30	36	42	48	53	1.1	61	54	48	42	35	28	22	15
22	30	38	47	55	64	72	80	1.3	90	82	72	63	53	44	34	25
33	44	55	66	77	88	99	110	1.5	124	111	99	87	74	62	50	38
47	61	75	89	103	117	130	145	1.7	164	147	131	116	100	84	68	54
64	81	98	115	132	149	166	184	1.9	207	187	168	149	130	111	92	73
83	103	124	145	165	186	207	228	2.1	256	233	209	186	163	140	117	95
105	130	154	178	203	227	252	277	2.3	310	282	255	228	201	174	147	120
130	159	187	216	244	273	302	331	2.5	370	339	307	275	243	211	179	148
158	191	224	257	290	323	356	390	2.7	435	399	363	326	290	253	216	179
190	228	265	303	341	379	416	454	2.9				381	339	297	255	213
225	267	309	351	393	434	476		3.1						344	297	250

(2.0) (3.0) (4.0) (5.0) — (2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8% — Bottom Width in Feet								Flow Depth	Channel Grade - 1.0% — Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
20	28	36	44	52	60	68	75	1.1	88	79	70	60	51	42	33	24
31	42	54	65	76	88	99	110	1.3	127	114	101	88	76	63	50	37
46	61	76	91	106	121	135	150	1.5	172	155	138	121	105	88	71	54
65	84	102	121	140	159	177	196	1.7	224	202	181	160	138	117	95	74
87	110	133	156	179	202	225	248	1.9	282	256	230	203	177	151	124	98
113	140	168	195	223	250	278	305	2.1				252	221	189	157	126
143	175	207	239	271	303			2.3							193	156
177	214	250						2.5								
216	257							2.7								
								2.9								
								3.1								

(3.0) (4.0) (5.0) — (3.0) (4.0) (5.0)

Figure 6.14 -- Velocity in ft. per sec. shown as follows: ⌐___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES
"D" Retardance
Side Slope = 6:1

Channel Grade - 0.1% Bottom Width in Feet								Flow Depth	Channel Grade - 0.2% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
	2	4	6	8	10	12	14	1.1	26	23	20	18	15	12	9	6
6	8	10	13	15	17	20	22	1.3	40	36	32	28	24	20	16	12
10	13	16	20	23	26	30	33	1.5	58	53	47	41	36	30	25	20
16	20	24	29	34	38	43	48	1.7	82	74	67	59	51	44	37	30
24	29	35	41	47	53	59	65	1.9	108	99	89	80	70	61	52	43
34	40	48	55	62	70	77	85	2.1	139	127	115	104	92	80	69	58
45	53	62	71	80	90	98	108	2.3	174	160	146	132	118	104	90	76
58	68	79	90	101	112	123	134	2.5	213	196	180	163	147	130	113	97
73	86	98	111	124	137	150	163	2.7	256	237	218	198	179	160	140	121
90	105	120	135	150	165	180	195	2.9	303	281	259	237	215	193	171	149
109	127	144	161	178	195	212	230	3.1	354	329	304	280	255	230	205	181

(0.5) (1.0) (1.5) (2.0) (1.0) (2.0) (3.0)

Channel Grade - 0.3% Bottom Width in Feet								Flow Depth	Channel Grade - 0.4% Bottom Width in Feet							
4	6	8	10	12	14	16	18		18	16	14	12	10	8	6	4
9	13	17	21	24	28	32	36	1.1	45	40	36	31	26	22	17	12
16	22	28	34	39	45	51	56	1.3	70	63	56	49	42	35	28	21
26	34	42	50	58	65	73	81	1.5	99	89	80	70	61	52	43	33
39	50	60	70	80	90	100	110	1.7	133	121	109	97	85	73	61	49
55	68	80	93	105	118	130	143	1.9	172	157	142	127	112	98	83	68
74	90	105	120	135	150	165	180	2.1	216	198	180	162	144	126	108	91
97	115	133	151	168	186	204	222	2.3	265	244	223	202	181	160	139	118
124	145	165	186	207	227	248	269	2.5	320	295	271	246	222	197	173	149
155	178	202	226	249	273	297	321	2.7	380	352	324	296	268	240	212	184
189	216	243	270	297	324	351	378	2.9	446	414	382	350	318	286	254	223
225	256	287	317	347	378	409	440	3.1	518	482	446	410	374	338	302	267

(1.0) (2.0) (3.0) (1.0) (2.0) (3.0) (4.0)

Figure 6.15 -- Velocity in ft. per sec. shown as follows: ⌐___( )

CAPACITY OF TRAPEZOIDAL DIVERSION DITCHES

"D" Retardance

Side Slope = 6:1

Channel Grade - 0.5% — Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
15	20	26	32	37	42	48	54	1.1
26	34	42	50	58	66	74	82	1.3
40	51	61	72	83	94	104	115	1.5
58	72	86	99	113	126	140	154	1.7
80	97	114	131	147	165	182	199	1.9
106	127	147	168	188	209	229	250	2.1
137	161	186	210	234	259	283	307	2.3
172	200	229	257	285	314	342	370	2.5
210	244	275	309	342	374	407	439	2.7
257	293	329	366	403	440	477	514	2.9
307	348	387	430	467	512	553	595	3.1

(2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.6% — Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
62	55	49	43	36	30	24	18	1.1
93	84	75	66	57	48	39	30	1.3
130	118	106	94	82	70	58	46	1.5
173	158	142	127	112	97	82	66	1.7
223	204	185	166	148	129	110	91	1.9
279	256	234	211	189	166	144	121	2.1
342	315	289	262	236	209	183	156	2.3
412	381	351	320	289	258	227	196	2.5
489	452	417	382	347	312	276	241	2.7
	532	492	451	411	371	331	291	2.9
				481	436	390	346	3.1

(2.0) (3.0) (4.0) (5.0)

Channel Grade - 0.8% — Bottom Width in Feet								Flow Depth
4	6	8	10	12	14	16	18	
23	30	38	46	54	61	69	77	1.1
38	49	60	71	81	92	103	114	1.3
58	72	87	101	115	130	144	158	1.5
83	101	119	137	155	173	191	209	1.7
113	135	157	179	201	223	245	267	1.9
148	174	202	227	254	280	306	333	2.1
188	219	250	281	312	344	375	406	2.3
233	270	306	342	378	414	451	487	2.5
								2.7
								2.9
								3.1

(2.0) (3.0) (4.0) (5.0)

Channel Grade - 1.0% — Bottom Width in Feet								Flow Depth
18	16	14	12	10	8	6	4	
90	81	72	63	54	45	36	28	1.1
134	121	109	96	83	70	58	45	1.3
183	166	150	133	117	100	84	67	1.5
242	220	199	178	157	136	115	94	1.7
306	280	255	229	203	177	152	126	1.9
	349	318	287	257	226	194	164	2.1
								2.3
								2.5
								2.7
								2.9
								3.1

(3.0) (4.0) (5.0)

Figure 6.16 -- Velocity in ft. per sec. shown as follows: ⌐_____( )

*HYDRAULIC RADIUS FOR OUT OF CHANNEL FLOWS FOR DIVERSIONS WITH GIVEN BOTTOM WIDTHS AND CHANNEL FLOW DEPTHS

Land Slope and Side Slopes	Channel Flow Depth	Channel Bottom Width - Feet							
		4	6	8	10	12	14	16	18
1% Land Slope 2:1 Side Slopes	1.3	---	---	.50	.52	.54	.56	.58	.60
	1.5	.50	.53	.55	.58	.60	.62	.64	.66
	1.7	.55	.58	.60	.63	.65	.67	.69	.72
	1.9	.60	.63	.65	.68	.70	.72	.75	.78
	2.1	.65	.68	.70	.73	.75	.78	.81	.84
	2.3	.69	.72	.75	.78	.81	.84	.87	.90
	2.5	.74	.77	.80	.83	.86	.89	.92	.95
	2.7	.79	.82	.85	.89	.92	.95	.98	1.01
	2.9	.84	.87	.90	.94	.97	1.01	1.04	1.07
	3.1	.88	.92	.95	.99	1.02	1.06	1.09	1.12
1% Land Slope 3:1 Side Slopes	1.3	---	---	---	---	.51	.53	.54	.56
	1.5	---	---	.52	.54	.56	.58	.60	.62
	1.7	.53	.55	.57	.59	.61	.63	.65	.67
	1.9	.57	.59	.61	.64	.66	.68	.70	.72
	2.1	.61	.64	.66	.68	.70	.73	.75	.78
	2.3	.66	.68	.70	.72	.75	.78	.80	.83
	2.5	.71	.73	.75	.78	.81	.83	.86	.89
	2.7	.75	.77	.79	.82	.85	.88	.91	.94
	2.9	.80	.82	.85	.88	.91	.94	.97	1.00
	3.1	.84	.87	.90	.93	.96	.99	1.02	1.05
1% Land Slope 4:1 Side Slopes	1.3	---	---	---	---	---	.50	.52	.54
	1.5	---	---	.50	.52	.53	.55	.57	.59
	1.7	.50	.52	.54	.56	.58	.60	.62	.64
	1.9	.55	.57	.59	.61	.63	.65	.67	.69
	2.1	.59	.61	.63	.66	.68	.70	.72	.74
	2.3	.64	.66	.69	.71	.73	.75	.77	.79
	2.5	.68	.70	.73	.75	.78	.80	.82	.84
	2.7	.73	.75	.78	.80	.83	.85	.87	.89
	2.9	.77	.79	.82	.84	.87	.89	.92	.94
	3.1	.81	.83	.86	.88	.91	.94	.97	.99
1% Land Slope 6:1 Side Slopes	1.3	---	---	---	---	---	---	---	.50
	1.5	---	---	---	---	.50	.52	.53	.55
	1.7	---	---	.51	.52	.54	.56	.57	.59
	1.9	.52	.54	.55	.57	.58	.60	.62	.64
	2.1	.56	.58	.59	.61	.63	.65	.66	.68
	2.3	.60	.62	.64	.66	.67	.69	.70	.72
	2.5	.64	.66	.68	.70	.72	.74	.75	.77
	2.7	.68	.70	.72	.74	.76	.78	.79	.81
	2.9	.72	.74	.76	.78	.80	.82	.83	.85
	3.1	.76	.78	.80	.82	.84	.86	.88	.90

*-Based on only that portion of out of channel flow where flow depth is 0.5 feet or greater and balanced cut-fill diversion cross-section. Cut-fill balance ratio--1.25:1.00

Figure 6.17

*HYDRAULIC RADIUS FOR OUT OF CHANNEL FLOW FOR DIVERSIONS WITH GIVEN BOTTOM WIDTHS AND CHANNEL FLOW DEPTHS

Land Slope and Side Slopes	Channel Flow Depth	Channel Bottom Width - Feet							
		4	6	8	10	12	14	16	18
2% Land Slope 2:1 Side Slopes	1.3	---	---	---	---	---	---	.50	.53
	1.5	---	---	---	---	.50	.53	.56	.59
	1.7	---	---	.50	.52	.55	.58	.61	.64
	1.9	.50	.53	.55	.58	.61	.64	.67	.70
	2.1	.55	.58	.61	.64	.67	.70	.73	.76
	2.3	.60	.63	.66	.69	.72	.75	.78	.81
	2.5	.65	.68	.71	.74	.78	.81	.84	.87
	2.7	.70	.73	.76	.79	.83	.86	.90	.93
	2.9	.75	.78	.81	.84	.88	.91	.95	.98
	3.1	.80	.83	.86	.90	.93	.97	1.01	1.04
2% Land Slope 3:1 Side Slopes	1.5	---	---	---	---	---	.50	.53	.55
	1.7	---	---	---	.51	.53	.55	.58	.60
	1.9	---	.50	.53	.55	.58	.60	.63	.65
	2.1	.51	.54	.57	.59	.62	.65	.68	.70
	2.3	.56	.59	.62	.64	.67	.70	.73	.75
	2.5	.60	.63	.66	.69	.71	.74	.77	.80
	2.7	.65	.68	.71	.74	.76	.79	.82	.85
	2.9	.69	.72	.75	.78	.81	.84	.87	.90
	3.1	.74	.77	.80	.83	.86	.89	.92	.95
2% Land Slope 4:1 Side Slopes	1.7	---	---	---	---	---	.51	.53	.55
	1.9	---	---	---	.51	.53	.55	.57	.59
	2.1	.49	.51	.53	.55	.58	.60	.62	.64
	2.3	.53	.56	.58	.60	.62	.64	.66	.68
	2.5	.57	.60	.62	.65	.67	.69	.71	.73
	2.7	.61	.64	.66	.69	.71	.73	.75	.77
	2.9	.65	.68	.70	.73	.75	.78	.80	.82
	3.1	.69	.72	.74	.77	.79	.82	.84	.87
2% Land Slope 6:1 Side Slopes	2.1	---	---	---	---	.50	.52	.53	.54
	2.3	---	.50	.51	.53	.54	.56	.57	.58
	2.5	.52	.54	.55	.57	.58	.60	.61	.62
	2.7	.55	.57	.58	.60	.61	.63	.65	.66
	2.9	.59	.61	.62	.64	.65	.67	.69	.70
	3.1	.62	.64	.65	.67	.69	.70	.72	.74
3% Land Slope 2:1 Side Slopes	1.5	---	---	---	---	---	---	---	.51
	1.7	---	---	---	---	.51	.53	.55	.56
	1.9	---	---	.52	.54	.56	.58	.60	.62
	2.1	.52	.55	.57	.59	.61	.63	.65	.67
	2.3	.56	.59	.61	.63	.66	.68	.70	.72
	2.5	.60	.63	.65	.68	.70	.73	.76	.78
	2.7	.64	.67	.69	.72	.75	.78	.81	.83
	2.9	.68	.71	.74	.77	.80	.83	.86	.88
	3.1	.72	.76	.79	.82	.85	.88	.91	.94
3% Land Slope 3:1 Side Slopes	1.7	---	---	---	---	---	---	---	.50
	1.9	---	---	---	---	---	.51	.53	.55
	2.1	---	---	.50	.52	.54	.56	.58	.60
	2.3	.50	.52	.54	.56	.58	.60	.62	.64
	2.5	.53	.56	.58	.60	.63	.65	.67	.69
	2.7	.57	.60	.62	.64	.67	.69	.71	.73
	2.9	.60	.63	.65	.68	.71	.73	.76	.78
	3.1	.64	.67	.69	.72	.75	.78	.80	.83

Figure 6.17.1

CROSS-SECTIONAL AREA AND VELOCITY FOR GIVEN HYDRAULIC RADIUS AND GRADE OUT OF CHANNEL FLOW

Hyd. Radius	"C" RETARDANCE Velocity of Flow - Ft/Sec for Following Diversion Grades - Ft/100'								*Cross-Sectional Area for Following Land Slopes			"D" RETARDANCE Velocity of Flow - Ft/Sec for Following Diversion Grades - Ft/100'							
	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1%	2%	3%	0.1	0.2	0.3	0.4	0.5	0.6	0.8	1.0
.50	---	---	---	---	---	---	---	---	0.0	0.0	0.0	---	---	0.4	0.5	0.6	0.8	1.1	1.4
.52	---	---	---	---	---	---	---	---	2.1	1.0	0.7	---	---	0.4	0.6	0.7	0.9	1.2	1.5
.54	---	---	---	---	---	---	---	0.3	4.3	2.2	1.4	---	0.3	0.4	0.6	0.8	1.0	1.3	1.6
.56	---	---	---	---	---	---	---	0.4	6.7	3.4	2.2	---	0.3	0.5	0.7	0.9	1.1	1.4	1.7
.58	---	---	---	---	---	---	0.3	0.5	9.3	4.6	3.1	---	0.4	0.5	0.7	0.9	1.1	1.5	1.8
.60	---	---	---	---	---	---	0.4	0.7	12.0	6.0	4.0	---	0.4	0.6	0.8	1.0	1.2	1.6	1.9
.62	---	---	---	---	---	0.2	0.5	0.8	14.9	7.4	5.0	---	0.4	0.6	0.9	1.1	1.3	1.7	2.0
.64	---	---	---	---	---	0.3	0.6	0.9	17.9	9.0	6.0	---	0.5	0.7	1.0	1.2	1.4	1.8	2.1
.66	---	---	---	---	---	0.4	0.8	1.1	21.1	10.6	7.1	---	0.5	0.7	1.0	1.2	1.5	1.9	2.3
.68	---	---	---	---	0.3	0.5	0.9	1.2	24.5	12.3	8.2	---	0.5	0.8	1.1	1.3	1.5	2.0	2.4
.70	---	---	---	0.2	0.4	0.6	1.0	1.4	28.0	14.0	9.3	0.3	0.6	0.8	1.1	1.4	1.6	2.1	2.5
.72	---	---	---	0.3	0.5	0.7	1.1	1.5	31.7	15.8	10.5	0.3	0.6	0.9	1.2	1.5	1.7	2.2	2.6
.74	---	---	---	0.4	0.6	0.8	1.2	1.6	35.5	17.8	11.8	0.3	0.7	1.0	1.3	1.5	1.8	2.3	2.7
.76	---	---	---	0.4	0.7	0.9	1.4	1.8	39.5	19.8	13.2	0.3	0.7	1.0	1.3	1.6	1.9	2.4	2.8
.78	---	---	---	0.5	0.7	1.0	1.5	1.9	43.7	21.8	14.6	0.4	0.8	1.1	1.4	1.7	2.0	2.5	2.9
.80	---	---	0.3	0.6	0.8	1.1	1.6	2.1	48.0	24.0	16.0	0.4	0.8	1.1	1.5	1.8	2.1	2.6	3.0
.82	---	---	0.4	0.6	0.9	1.2	1.7	2.2	52.5	26.2	17.5	0.4	0.8	1.2	1.5	1.8	2.1	2.6	3.1
.84	---	---	0.4	0.7	1.0	1.3	1.8	2.3	57.1	28.6	19.0	0.4	0.9	1.3	1.6	1.9	2.2	2.7	3.2
.86	---	---	0.5	0.8	1.1	1.4	2.0	2.5	61.9	31.0	20.6	0.5	0.9	1.3	1.7	2.0	2.3	2.8	3.3
.88	---	0.2	0.5	0.9	1.2	1.5	2.1	2.6	66.9	33.4	22.3	0.5	1.0	1.4	1.7	2.1	2.4	2.9	3.4
.90	---	0.3	0.6	0.9	1.3	1.6	2.2	2.7	72.0	36.0	24.0	0.5	1.0	1.4	1.8	2.1	2.4	3.0	3.5
.92	---	0.3	0.7	1.0	1.4	1.7	2.3	2.9	77.3	38.6	25.8	0.5	1.1	1.5	1.8	2.2	2.5	3.1	3.6
.94	---	0.4	0.7	1.1	1.4	1.8	2.4	3.0	82.7	41.4	27.6	0.6	1.1	1.5	1.9	2.3	2.6	3.2	3.7
.96	---	0.4	0.8	1.2	1.5	1.9	2.5	3.1	88.3	44.2	29.4	0.6	1.1	1.6	2.0	2.3	2.7	3.3	3.8
.98	---	0.5	0.9	1.3	1.6	2.0	2.6	3.2	94.1	47.0	31.3	0.6	1.2	1.6	2.0	2.4	2.8	3.4	3.9
1.00	---	0.5	0.9	1.3	1.7	2.1	2.7	3.3	100.0	50.0	33.3	0.7	1.2	1.7	2.1	2.5	2.9	3.5	4.0
1.02	---	0.6	1.0	1.4	1.8	2.2	2.8	3.4	106.1	53.0	35.4	0.7	1.3	1.7	2.2	2.6	2.9	3.5	4.1
1.04	---	0.6	1.1	1.5	1.9	2.3	2.9	3.5	112.3	56.2	37.5	0.7	1.3	1.8	2.2	2.6	3.0	3.6	4.2
1.06	---	0.7	1.2	1.6	2.0	2.4	3.1	3.7	118.7	59.4	39.6	0.7	1.3	1.9	2.3	2.7	3.1	3.7	4.3
1.08	---	0.7	1.2	1.6	2.1	2.5	3.2	3.8	125.3	62.6	41.8	0.8	1.4	1.9	2.3	2.7	3.1	3.8	4.4
1.10	0.2	0.8	1.3	1.7	2.2	2.6	3.3	3.9	132.0	66.0	44.0	0.8	1.4	2.0	2.4	2.8	3.2	3.9	4.5
1.12	0.4	0.9	1.4	1.8	2.3	2.7	3.4	4.0	138.9	69.4	46.3	0.8	1.4	2.0	2.4	2.9	3.3	4.0	4.6

*-Based only on that area where depth of flow is 0.5 ft. or greater.

Figure 6.18

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

1% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	0.9	5.3	0.8	6.2	0.8	7.0	0.7	7.8	0.7	8.5	0.6	9.1	0.6	9.6	0.5	10.1
1.8	1.0	6.2	0.9	7.1	0.8	8.0	0.8	8.9	0.7	9.8	0.7	10.5	0.7	11.2	0.6	11.6
2.0	1.1	7.1	1.0	8.1	0.9	9.1	0.9	10.1	0.8	11.1	0.8	11.9	0.7	12.7	0.7	13.2
2.2	1.2	8.0	1.1	9.2	1.0	10.3	1.0	11.4	0.9	12.5	0.9	13.4	0.8	14.3	0.8	14.9
2.4	1.4	9.0	1.2	10.3	1.1	11.5	1.1	12.7	1.0	13.9	1.0	14.9	0.9	15.9	0.8	16.6
2.6	1.5	10.0	1.3	11.4	1.2	12.8	1.2	14.1	1.1	15.4	1.0	16.5	1.0	17.5	0.9	18.4
2.8	1.6	11.1	1.5	12.6	1.3	14.1	1.3	15.5	1.2	16.9	1.1	18.1	1.1	19.2	1.0	20.2
3.0	1.7	12.3	1.6	13.9	1.4	15.5	1.4	17.0	1.3	18.5	1.2	19.8	1.2	21.0	1.1	22.1
3.2	1.8	13.5	1.7	15.2	1.5	16.9	1.5	18.5	1.4	20.1	1.3	21.5	1.2	22.8	1.2	24.0
3.4	1.9	14.8	1.8	16.6	1.6	18.4	1.6	20.1	1.5	21.8	1.4	23.3	1.3	24.7	1.3	26.0
3.6	2.0	16.1	1.9	18.0	1.7	19.9	1.7	21.7	1.6	23.5	1.5	25.0	1.4	26.5	1.3	28.0
3.8	2.1	17.5	2.0	19.5	1.8	21.5	1.8	23.4	1.7	25.3	1.6	26.9	1.5	28.5	1.4	30.1
4.0	2.2	18.9	2.1	21.1	1.9	23.2	1.9	25.2	1.8	27.1	1.7	28.9	1.6	30.6	1.5	32.3

2% Land Slope

1.6	1.0	5.6	0.9	6.5	0.8	7.4	0.8	8.3	0.7	9.1	0.7	9.8	0.6	10.5	0.6	11.2
1.8	1.1	6.5	1.0	7.5	0.9	8.5	0.8	9.5	0.8	10.5	0.7	11.3	0.7	12.1	0.7	12.8
2.0	1.2	7.4	1.1	8.6	1.0	9.7	0.9	10.8	0.9	11.9	0.8	12.8	0.8	13.7	0.8	14.5
2.2	1.3	8.4	1.2	9.7	1.1	10.9	1.0	12.1	1.0	13.3	0.9	14.3	0.9	15.3	0.8	16.2
2.4	1.4	9.5	1.3	10.9	1.2	12.2	1.1	13.5	1.1	14.8	1.0	15.9	1.0	17.0	0.9	18.0
2.6	1.5	10.6	1.4	12.1	1.3	13.5	1.2	15.0	1.2	16.4	1.1	17.6	1.0	18.7	1.0	19.9
2.8	1.6	11.8	1.5	13.4	1.4	14.9	1.3	16.5	1.3	18.0	1.2	19.3	1.1	20.5	1.1	21.8
3.0	1.7	13.0	1.6	14.7	1.5	16.3	1.4	18.0	1.3	19.6	1.3	21.0	1.2	22.3	1.2	23.7
3.2	1.9	14.2	1.7	16.0	1.6	17.8	1.5	19.6	1.4	21.3	1.4	22.8	1.3	24.2	1.2	25.7
3.4	2.0	15.5	1.8	17.4	1.7	19.3	1.6	21.2	1.5	23.0	1.5	24.6	1.4	26.2	1.3	27.8
3.6	2.1	16.8	1.9	18.9	1.8	20.9	1.7	22.9	1.6	24.8	1.6	26.5	1.5	28.2	1.4	29.9
3.8	2.2	18.2	2.1	20.4	1.9	22.6	1.8	24.7	1.7	26.7	1.7	28.5	1.6	30.3	1.5	32.1
4.0	2.3	19.7	2.2	22.0	2.0	24.3	1.9	26.5	1.8	28.6	1.8	30.6	1.7	32.5	1.6	34.4

1/ - In Feet 2/ - In Square Feet Per Foot

USDA-SCS-LINCOLN, NEBR. 1961

5.L-17,830.1

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

3% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.0	5.9	0.9	6.9	0.9	7.9	0.8	8.9	0.8	9.8	0.7	10.7	0.7	11.5	0.6	12.3
1.8	1.1	6.8	1.0	8.0	1.0	9.1	0.9	10.2	0.9	11.2	0.8	12.2	0.8	13.1	0.7	13.9
2.0	1.2	7.8	1.1	9.1	1.1	10.3	1.0	11.5	0.9	12.7	0.9	13.8	0.8	14.8	0.8	15.7
2.2	1.3	8.8	1.2	10.2	1.2	11.6	1.1	12.9	1.0	14.2	1.0	15.4	0.9	16.5	0.9	17.5
2.4	1.5	9.9	1.4	11.4	1.3	12.9	1.2	14.3	1.1	15.7	1.1	17.0	1.0	18.3	1.0	19.4
2.6	1.6	11.0	1.5	12.7	1.4	14.3	1.3	15.8	1.2	17.3	1.2	18.7	1.1	20.1	1.1	21.3
2.8	1.7	12.2	1.6	14.0	1.5	15.7	1.4	17.4	1.3	19.0	1.3	20.5	1.2	22.0	1.2	23.3
3.0	1.8	13.4	1.7	15.3	1.6	17.2	1.5	19.0	1.4	20.7	1.4	22.3	1.3	23.9	1.2	25.3
3.2	1.9	14.7	1.8	16.7	1.7	18.7	1.6	20.6	1.5	22.4	1.4	24.2	1.4	25.9	1.3	27.4
3.4	2.0	16.1	1.9	18.2	1.8	20.3	1.7	22.3	1.6	24.3	1.5	26.2	1.5	27.9	1.4	29.6
3.6	2.1	17.5	2.0	19.8	1.9	22.0	1.8	24.1	1.7	26.2	1.6	28.2	1.6	30.0	1.5	31.9
3.8	2.3	19.0	2.1	21.4	2.0	23.8	1.9	26.0	1.8	28.2	1.7	30.3	1.7	32.2	1.6	34.2
4.0	2.4	20.6	2.2	23.1	2.1	25.6	2.0	27.9	1.9	30.2	1.8	32.4	1.8	34.5	1.7	36.6

4% Land Slope

1.6	1.1	6.3	1.0	7.4	0.9	8.5	0.8	9.6	0.8	10.6	0.8	11.6	0.7	12.5	0.7	13.4
1.8	1.2	7.2	1.1	8.5	1.0	9.7	0.9	10.9	0.9	12.1	0.9	13.2	0.8	14.2	0.8	15.2
2.0	1.3	8.2	1.2	9.6	1.1	11.0	1.0	12.3	1.0	13.6	0.9	14.8	0.9	15.9	0.9	17.0
2.2	1.4	9.2	1.3	10.8	1.2	12.3	1.1	13.8	1.1	15.2	1.0	16.5	1.0	17.7	1.0	18.9
2.4	1.5	10.3	1.4	12.0	1.3	13.7	1.2	15.3	1.2	16.8	1.1	18.2	1.1	19.5	1.0	20.9
2.6	1.6	11.5	1.5	13.4	1.4	15.1	1.3	16.8	1.3	18.4	1.2	19.9	1.2	21.4	1.1	22.9
2.8	1.7	12.7	1.6	14.7	1.5	16.6	1.4	18.4	1.4	20.1	1.3	21.8	1.3	23.4	1.2	25.0
3.0	1.8	13.9	1.7	16.1	1.6	18.2	1.5	20.1	1.5	21.9	1.4	23.7	1.4	25.4	1.3	27.1
3.2	2.0	15.3	1.8	17.6	1.7	19.8	1.6	21.8	1.6	23.7	1.5	25.6	1.4	27.5	1.4	29.3
3.4	2.1	16.7	1.9	19.1	1.8	21.5	1.8	23.6	1.7	25.6	1.6	27.7	1.5	29.7	1.5	31.6
3.6	2.2	18.2	2.1	20.7	1.9	23.2	1.9	25.4	1.8	27.6	1.7	29.8	1.6	31.9	1.6	33.9
3.8	2.3	19.8	2.2	22.4	2.1	25.0	2.0	27.4	1.9	29.7	1.8	32.0	1.7	34.2	1.7	36.3
4.0	2.4	21.5	2.3	24.2	2.2	26.9	2.1	29.4	2.0	31.9	1.9	34.3	1.8	36.6	1.8	38.9

1/ - In Feet 2/ - In Square Feet Per Foot

5,L-17,830.2

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

5% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.1	6.7	1.0	7.9	0.9	9.1	0.9	10.3	0.8	11.4	0.8	12.5	0.8	13.6	0.7	14.7
1.8	1.2	7.6	1.1	9.0	1.1	10.4	1.0	11.7	0.9	12.9	0.9	14.2	0.9	15.4	0.8	16.6
2.0	1.3	8.6	1.2	10.2	1.2	11.8	1.1	13.2	1.0	14.5	1.0	15.9	1.0	17.2	0.9	18.5
2.2	1.4	9.7	1.3	11.4	1.3	13.2	1.2	14.7	1.1	16.2	1.1	17.7	1.0	19.1	1.0	20.5
2.4	1.6	10.9	1.5	12.7	1.4	14.6	1.3	16.3	1.2	17.9	1.2	19.5	1.1	21.0	1.1	22.5
2.6	1.7	12.1	1.6	14.1	1.5	16.1	1.4	17.9	1.3	19.7	1.3	21.4	1.2	23.0	1.2	24.6
2.8	1.8	13.4	1.7	15.5	1.6	17.6	1.5	19.6	1.4	21.5	1.4	23.3	1.3	25.0	1.3	26.8
3.0	1.9	14.8	1.8	17.0	1.7	19.2	1.6	21.3	1.5	23.3	1.5	25.2	1.4	27.1	1.4	29.1
3.2	2.0	16.2	1.9	18.6	1.8	20.9	1.7	23.1	1.6	25.2	1.6	27.3	1.5	29.3	1.5	31.4
3.4	2.1	17.7	2.0	20.2	1.9	22.6	1.8	24.9	1.7	27.2	1.7	29.4	1.6	31.6	1.6	33.8
3.6	2.3	19.2	2.1	21.9	2.0	24.4	1.9	26.9	1.9	29.3	1.8	31.6	1.7	33.9	1.6	36.2
3.8	2.4	20.8	2.3	23.6	2.1	26.3	2.0	28.9	2.0	31.4	1.9	33.8	1.8	36.3	1.7	38.7
4.0	2.5	22.5	2.4	25.4	2.3	28.3	2.1	31.0	2.1	33.6	2.0	36.2	1.9	38.7	1.8	41.2

6% Land Slope

1.6	1.1	7.1	1.1	8.4	1.0	9.7	0.9	11.0	0.9	12.3	0.9	13.6	0.8	14.8	0.8	16.0
1.8	1.2	8.1	1.2	9.6	1.1	11.1	1.0	12.5	1.0	13.9	0.9	15.3	0.9	16.6	0.9	17.9
2.0	1.4	9.2	1.3	10.9	1.2	12.5	1.1	14.0	1.1	15.6	1.0	17.1	1.0	18.5	1.0	19.9
2.2	1.5	10.4	1.4	12.2	1.3	13.9	1.2	15.6	1.2	17.3	1.1	18.9	1.1	20.4	1.1	22.0
2.4	1.6	11.6	1.5	13.5	1.4	15.4	1.4	17.3	1.3	19.1	1.2	20.8	1.2	22.4	1.1	24.1
2.6	1.7	12.8	1.6	14.9	1.5	17.0	1.5	19.0	1.4	20.9	1.3	22.7	1.3	24.5	1.2	26.3
2.8	1.8	14.1	1.7	16.4	1.6	18.6	1.6	20.7	1.5	22.8	1.4	24.7	1.4	26.6	1.3	28.5
3.0	2.0	15.5	1.9	17.9	1.8	20.3	1.7	22.5	1.6	24.8	1.5	26.8	1.5	28.8	1.4	30.8
3.2	2.1	16.9	2.0	19.5	1.9	22.0	1.8	24.4	1.7	26.8	1.6	29.0	1.6	31.1	1.5	33.2
3.4	2.2	18.4	2.1	21.1	2.0	23.8	1.9	26.4	1.8	28.9	1.8	31.2	1.7	33.5	1.6	35.7
3.6	2.3	20.0	2.2	22.9	2.1	25.7	2.0	28.4	1.9	31.0	1.9	33.5	1.8	35.9	1.7	38.3
3.8	2.4	21.7	2.3	24.7	2.2	27.7	2.1	30.5	2.0	33.2	2.0	35.8	1.9	38.4	1.8	40.9
4.0	2.6	23.5	2.4	26.6	2.3	29.7	2.2	32.6	2.1	35.4	2.1	38.2	2.0	40.9	1.9	43.6

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17,830.3

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

7% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet													
	4'		6'		8'		10'		12'		14'		16'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.2	7.5	1.1	9.0	1.0	10.4	1.0	11.8	0.9	13.2	0.9	14.6	0.9	16.0
1.8	1.3	8.6	1.2	10.2	1.1	11.8	1.1	13.4	1.0	14.9	1.0	16.4	1.0	17.9
2.0	1.4	9.7	1.3	11.5	1.2	13.2	1.2	15.0	1.1	16.6	1.1	18.3	1.1	19.9
2.2	1.5	10.9	1.4	12.9	1.4	14.7	1.3	16.6	1.2	18.4	1.2	20.2	1.2	22.0
2.4	1.6	12.2	1.5	14.3	1.5	16.3	1.4	18.3	1.3	20.3	1.3	22.2	1.3	24.1
2.6	1.8	13.5	1.7	15.8	1.6	18.0	1.5	20.1	1.4	22.2	1.4	24.3	1.4	26.3
2.8	1.9	14.9	1.8	17.3	1.7	19.7	1.6	22.0	1.5	24.2	1.5	26.4	1.5	28.5
3.0	2.0	16.3	1.9	18.9	1.8	21.4	1.7	23.9	1.7	26.3	1.6	28.6	1.6	30.8
3.2	2.1	17.8	2.0	20.6	1.9	23.2	1.8	25.9	1.8	28.4	1.7	30.8	1.7	33.2
3.4	2.2	19.4	2.1	22.3	2.0	25.1	2.0	27.9	1.9	30.5	1.8	33.1	1.8	35.6
3.6	2.4	21.0	2.3	24.1	2.2	27.1	2.1	30.0	2.0	32.7	1.9	35.4	1.9	38.1
3.8	2.5	22.7	2.4	26.0	2.3	29.1	2.2	32.1	2.1	35.0	2.0	37.8	2.0	40.6
4.0	2.6	24.5	2.5	27.9	2.4	31.2	2.3	34.3	2.2	37.3	2.1	40.3	2.1	43.2

8% Land Slope

1.6	1.2	7.9	1.1	9.5	1.1	11.1	1.0	12.7	1.0	14.2	0.9	15.8	0.9	17.3
1.8	1.3	9.0	1.3	10.8	1.2	12.6	1.1	14.3	1.1	15.9	1.0	17.6	1.0	19.2
2.0	1.5	10.2	1.4	12.2	1.3	14.1	1.2	15.9	1.2	17.7	1.1	19.5	1.1	21.2
2.2	1.6	11.5	1.5	13.6	1.4	15.7	1.3	17.6	1.3	19.5	1.2	21.4	1.2	23.3
2.4	1.7	12.8	1.6	15.1	1.5	17.3	1.5	19.3	1.4	21.4	1.4	23.5	1.3	25.5
2.6	1.8	14.2	1.7	16.6	1.6	19.0	1.6	21.2	1.5	23.4	1.5	25.7	1.4	27.8
2.8	1.9	15.6	1.8	18.2	1.7	20.7	1.7	23.1	1.6	25.5	1.6	27.9	1.5	30.2
3.0	2.1	17.1	2.0	19.9	1.9	22.5	1.8	25.1	1.7	27.7	1.7	30.2	1.6	32.6
3.2	2.2	18.7	2.1	21.6	2.0	24.4	1.9	27.2	1.8	29.9	1.8	32.5	1.7	35.1
3.4	2.3	20.3	2.2	23.4	2.1	26.4	2.0	29.3	1.9	32.2	1.9	34.9	1.8	37.6
3.6	2.4	22.0	2.3	25.3	2.2	28.5	2.1	31.5	2.1	34.5	2.0	37.4	1.9	40.2
3.8	2.6	23.8	2.4	27.2	2.3	30.6	2.3	33.8	2.2	36.9	2.1	39.9	2.0	42.9
4.0	2.7	25.6	2.6	29.2	2.5	32.7	2.4	36.1	2.3	39.3	2.2	42.5	2.2	45.7

1/ - In Feet 2/ - In Square Feet Per Foot

5,L-17,830.4

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

9% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet											
	4'		6'		8'		10'		12'		14'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.3	8.3	1.2	10.1	1.1	11.8	1.1	13.5	1.0	15.2	1.0	16.9
1.8	1.4	9.4	1.3	11.4	1.2	13.3	1.2	15.2	1.1	17.0	1.1	18.8
2.0	1.5	10.6	1.4	12.8	1.4	14.9	1.3	16.9	1.2	18.9	1.2	20.8
2.2	1.6	11.9	1.5	14.3	1.5	16.5	1.4	18.7	1.3	20.8	1.3	22.9
2.4	1.7	13.3	1.7	15.8	1.6	18.2	1.5	20.5	1.4	22.8	1.4	25.1
2.6	1.9	14.8	1.8	17.4	1.7	20.0	1.6	22.4	1.6	24.9	1.5	27.4
2.8	2.0	16.3	1.9	19.1	1.8	21.8	1.7	24.4	1.7	27.1	1.6	29.7
3.0	2.1	17.9	2.0	20.8	1.9	23.7	1.9	26.5	1.8	29.4	1.7	32.1
3.2	2.2	19.5	2.1	22.6	2.0	25.7	2.0	28.7	1.9	31.6	1.8	34.5
3.4	2.4	21.2	2.3	24.5	2.2	27.8	2.1	30.9	2.0	34.0	1.9	37.0
3.6	2.5	23.0	2.4	26.4	2.3	29.9	2.2	33.2	2.1	36.4	2.0	39.6
3.8	2.6	24.8	2.5	28.4	2.4	32.1	2.3	35.5	2.2	38.9	2.2	42.2
4.0	2.7	26.7	2.6	30.5	2.5	34.3	2.4	37.9	2.4	41.4	2.3	44.9

10% Land Slope

1.6	1.3	8.8	1.2	10.7	1.2	12.6	1.1	14.4	1.1	16.2	1.0	18.0
1.8	1.4	10.0	1.3	12.1	1.3	14.1	1.2	16.1	1.2	18.1	1.1	20.0
2.0	1.5	11.2	1.5	13.5	1.4	15.7	1.3	17.9	1.3	20.0	1.2	22.1
2.2	1.7	12.6	1.6	15.0	1.5	17.4	1.4	19.8	1.4	22.0	1.3	24.3
2.4	1.8	14.0	1.7	16.6	1.6	19.2	1.6	21.7	1.5	24.1	1.4	26.5
2.6	1.9	15.5	1.8	18.3	1.7	21.1	1.7	23.7	1.6	26.3	1.6	28.8
2.8	2.0	17.1	1.9	20.1	1.9	23.0	1.8	25.8	1.7	28.6	1.7	31.3
3.0	2.2	18.8	2.1	21.9	2.0	25.0	1.9	28.0	1.8	30.9	1.8	33.8
3.2	2.3	20.5	2.2	23.8	2.1	27.0	2.0	30.2	2.0	33.3	1.9	36.4
3.4	2.4	22.3	2.3	25.7	2.2	29.1	2.2	32.5	2.1	35.8	2.0	39.0
3.6	2.5	24.1	2.4	27.7	2.3	31.3	2.3	34.8	2.2	38.3	2.1	41.7
3.8	2.7	26.0	2.6	29.8	2.5	33.6	2.4	37.2	2.3	40.9	2.2	44.5
4.0	2.8	27.9	2.7	31.9	2.6	35.9	2.5	39.7	2.4	43.5	2.4	47.3

1/ - In Feet 2/ - In Square Feet Per Foot

5,L-17,830.5

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

11% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet									
	4'		6'		8'		10'		12'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.3	9.2	1.3	11.3	1.2	13.4	1.2	15.4	1.1	17.3
1.8	1.4	10.4	1.4	12.7	1.3	15.0	1.3	17.2	1.2	19.3
2.0	1.6	11.7	1.5	14.2	1.4	16.7	1.4	19.0	1.3	21.3
2.2	1.7	13.1	1.6	15.8	1.6	18.4	1.5	20.9	1.4	23.4
2.4	1.8	14.6	1.8	17.5	1.7	20.2	1.6	22.9	1.6	25.6
2.6	2.0	16.2	1.9	19.2	1.8	22.1	1.7	25.0	1.7	27.9
2.8	2.1	17.9	2.0	21.0	1.9	24.1	1.9	27.2	1.8	30.2
3.0	2.2	19.6	2.1	22.9	2.1	26.2	2.0	29.5	1.9	32.6
3.2	2.3	21.4	2.3	24.9	2.2	28.3	2.1	31.8	2.0	35.1
3.4	2.5	23.2	2.4	26.9	2.3	30.5	2.2	34.2	2.1	37.7
3.6	2.6	25.1	2.5	29.0	2.4	32.8	2.3	36.6	2.3	40.3
3.8	2.7	27.1	2.6	31.1	2.6	35.1	2.5	39.1	2.4	43.0
4.0	2.9	29.1	2.8	33.3	2.7	37.5	2.6	41.6	2.5	45.7

12% Land Slope

1.6	1.3	9.7	1.3	12.0	1.3	14.2	1.2	16.3	1.1	18.4
1.8	1.5	11.0	1.4	13.5	1.4	15.9	1.3	18.2	1.2	20.4
2.0	1.6	12.4	1.5	15.1	1.5	17.7	1.4	20.1	1.4	22.5
2.2	1.7	13.8	1.7	16.7	1.6	19.5	1.5	22.1	1.5	24.7
2.4	1.8	15.3	1.8	18.4	1.7	21.4	1.7	24.2	1.6	27.0
2.6	2.0	16.9	1.9	20.2	1.9	23.4	1.8	26.4	1.7	29.4
2.8	2.1	18.6	2.0	22.0	2.0	25.4	1.9	28.6	1.8	31.8
3.0	2.2	20.4	2.2	24.0	2.1	27.5	2.0	30.9	2.0	34.3
3.2	2.4	22.3	2.3	26.0	2.2	29.7	2.2	33.3	2.1	36.9
3.4	2.5	24.2	2.4	28.1	2.4	32.0	2.3	35.8	2.2	39.6
3.6	2.6	26.2	2.6	30.3	2.5	34.4	2.4	38.3	2.3	42.3
3.8	2.8	28.3	2.7	32.6	2.6	36.8	2.5	40.9	2.5	45.1
4.0	2.9	30.4	2.8	34.9	2.7	39.3	2.7	43.6	2.6	47.9

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17.830.6

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

13% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet							
	4'		6'		8'		10'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.4	10.2	1.3	12.6	1.3	15.0	1.2	17.3
1.8	1.5	11.5	1.5	14.2	1.4	16.8	1.4	19.3
2.0	1.6	12.9	1.6	15.8	1.5	18.6	1.5	21.4
2.2	1.8	14.4	1.7	17.5	1.7	20.5	1.6	23.5
2.4	1.9	16.0	1.8	19.3	1.8	22.5	1.7	25.7
2.6	2.0	17.7	2.0	21.2	1.9	24.5	1.9	28.0
2.8	2.2	19.4	2.1	23.1	2.0	26.7	2.0	30.3
3.0	2.3	21.2	2.2	25.1	2.2	28.9	2.1	32.7
3.2	2.4	23.2	2.4	27.2	2.3	31.2	2.2	35.2
3.4	2.6	25.2	2.5	29.4	2.4	33.5	2.3	37.7
3.6	2.7	27.3	2.6	31.6	2.5	35.9	2.5	40.3
3.8	2.8	29.4	2.8	33.9	2.7	38.4	2.6	42.9
4.0	3.0	31.7	2.9	36.4	2.8	41.0	2.7	45.6

14% Land Slope

1.6	1.4	10.7	1.4	13.4	1.3	16.0	1.3	18.6
1.8	1.5	12.1	1.5	15.0	1.5	17.8	1.4	20.6
2.0	1.7	13.6	1.6	16.7	1.6	19.7	1.5	22.7
2.2	1.8	15.1	1.8	18.4	1.7	21.7	1.7	24.9
2.4	1.9	16.7	1.9	20.2	1.8	23.7	1.8	27.2
2.6	2.1	18.4	2.0	22.2	2.0	25.9	1.9	29.6
2.8	2.2	20.3	2.1	24.2	2.1	28.1	2.0	32.0
3.0	2.3	22.2	2.3	26.3	2.2	30.4	2.2	34.5
3.2	2.5	24.2	2.4	28.5	2.4	32.8	2.3	37.0
3.4	2.6	26.3	2.5	30.8	2.5	35.2	2.4	39.6
3.6	2.8	28.5	2.7	33.2	2.6	37.7	2.5	42.3
3.8	2.9	30.8	2.8	35.6	2.7	40.3	2.6	45.1
4.0	3.0	33.1	3.0	38.1	2.9	43.0	2.8	47.9

1/ - In Feet 2/ - In Square Feet Per Foot

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
2:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

Channel Bottom Width - Feet

Total Height of Diversion Above Channel	15% Land Slope						16% Land Slope					
	4'		6'		8'		4'		6'		8'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.4	11.2	1.4	14.0	1.4	16.8	1.5	11.7	1.4	14.7	1.4	17.7
1.8	1.6	12.7	1.5	15.7	1.5	18.7	1.6	13.3	1.6	16.5	1.5	19.7
2.0	1.7	14.3	1.7	17.5	1.6	20.7	1.8	15.0	1.7	18.4	1.7	21.8
2.2	1.8	16.0	1.8	19.4	1.8	22.8	1.9	16.8	1.8	20.4	1.8	24.0
2.4	2.0	17.7	1.9	21.4	1.9	25.0	2.0	18.6	2.0	22.5	1.9	26.3
2.6	2.1	19.5	2.1	23.4	2.0	27.2	2.2	20.5	2.1	24.6	2.1	28.7
2.8	2.3	21.4	2.2	25.5	2.1	29.5	2.3	22.5	2.2	26.9	2.2	31.2
3.0	2.4	23.4	2.3	27.7	2.3	31.9	2.5	24.6	2.4	29.2	2.3	33.7
3.2	2.5	25.5	2.5	30.0	2.4	34.4	2.6	26.8	2.5	31.6	2.5	36.3
3.4	2.7	27.7	2.6	32.4	2.5	37.0	2.7	29.1	2.7	34.1	2.6	39.0
3.6	2.8	30.0	2.7	34.9	2.7	39.7	2.9	31.5	2.8	36.7	2.7	41.8
3.8	3.0	32.3	2.9	37.4	2.8	42.4	3.0	34.0	2.9	39.3	2.9	44.6
4.0	3.1	34.7	3.0	40.0	2.9	45.2	3.2	36.5	3.1	42.0	3.0	47.5

	17% Land Slope						18% Land Slope					
1.6	1.5	12.3	1.5	15.5	1.4	18.6	1.5	13.0	1.5	16.3	1.5	19.6
1.8	1.7	14.0	1.6	17.4	1.6	20.7	1.7	14.8	1.6	18.3	1.6	21.8
2.0	1.8	15.8	1.8	19.4	1.7	22.9	1.9	16.7	1.8	20.4	1.7	24.1
2.2	2.0	17.7	1.9	21.5	1.8	25.2	2.0	18.7	1.9	22.6	1.9	26.5
2.4	2.1	19.7	2.0	23.7	2.0	27.6	2.2	20.8	2.1	24.9	2.0	29.0
2.6	2.2	21.7	2.2	25.9	2.1	30.1	2.3	23.0	2.2	27.3	2.2	31.6
2.8	2.4	23.8	2.3	28.3	2.2	32.7	2.5	25.3	2.4	29.8	2.3	34.3
3.0	2.5	25.0	2.5	30.7	2.4	35.4	2.6	27.6	2.5	32.4	2.4	37.1
3.2	2.7	27.3	2.6	33.2	2.5	38.1	2.7	30.0	2.6	35.0	2.6	40.0
3.4	2.8	30.7	2.7	35.8	2.7	40.9	2.8	32.5	2.8	37.8	2.7	43.0
3.6	2.9	33.2	2.9	38.5	2.8	43.8	3.0	35.1	2.9	40.6	2.9	46.1
3.8	3.1	35.8	3.0	41.3	2.9	46.8	3.1	37.8	3.1	43.5	3.0	49.2
4.0	3.2	38.5	3.1	44.2	3.1	49.9	3.3	40.6	3.2	46.5	3.2	52.4

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17,830.8

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
3:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

1% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.0	6.6	0.9	7.4	0.8	8.2	0.7	8.9	0.7	9.6	0.7	10.2	0.6	10.8	0.6	11.4
1.8	1.1	7.6	1.0	8.6	0.9	9.5	0.8	10.3	0.8	11.1	0.8	11.8	0.7	12.5	0.7	13.2
2.0	1.2	8.7	1.1	9.9	1.0	10.9	0.9	11.9	0.9	12.8	0.8	13.6	0.8	14.4	0.8	15.2
2.2	1.3	9.9	1.2	11.3	1.1	12.4	1.1	13.5	1.0	14.6	0.9	15.5	0.9	16.4	0.8	17.3
2.4	1.4	11.2	1.3	12.7	1.2	14.0	1.2	15.2	1.1	16.4	1.0	17.4	1.0	18.4	0.9	19.4
2.6	1.5	12.6	1.4	14.2	1.3	15.7	1.3	17.0	1.2	18.3	1.1	19.4	1.1	20.5	1.0	21.6
2.8	1.6	14.1	1.5	15.8	1.4	17.4	1.4	18.8	1.3	20.2	1.2	21.4	1.2	22.6	1.1	23.8
3.0	1.7	15.7	1.6	17.4	1.5	19.1	1.5	20.7	1.4	22.2	1.3	23.5	1.3	24.8	1.2	26.1
3.2	1.8	17.3	1.7	19.1	1.6	20.9	1.6	22.6	1.5	24.2	1.4	25.7	1.4	27.1	1.3	28.5
3.4	1.9	19.0	1.8	20.9	1.7	22.8	1.7	24.6	1.6	26.3	1.5	27.9	1.5	29.4	1.4	30.9
3.6	2.0	20.7	1.9	22.7	1.8	24.7	1.8	26.6	1.7	28.5	1.6	30.2	1.5	31.8	1.5	33.4
3.8	2.2	22.5	2.0	24.6	1.9	26.7	1.9	28.8	1.8	30.8	1.7	32.6	1.6	34.3	1.6	36.0
4.0	2.3	24.4	2.2	26.6	2.1	28.8	2.0	31.0	1.9	33.1	1.8	35.0	1.7	36.8	1.7	38.6

2% Land Slope

1.6	1.0	6.9	0.9	7.9	0.8	8.8	0.8	9.7	0.8	10.6	0.7	11.4	0.7	12.1	0.6	12.8
1.8	1.1	8.1	1.0	9.2	1.0	10.2	0.9	11.2	0.9	12.2	0.8	13.1	0.8	14.0	0.7	14.8
2.0	1.2	9.3	1.1	10.6	1.1	11.7	1.0	12.8	1.0	14.0	0.9	15.0	0.9	16.0	0.8	16.9
2.2	1.3	10.6	1.3	12.0	1.2	13.3	1.1	14.6	1.1	15.8	1.0	17.0	0.9	18.1	0.9	19.1
2.4	1.4	12.0	1.4	13.5	1.3	14.9	1.2	16.4	1.2	17.7	1.1	19.0	1.0	20.3	1.0	21.4
2.6	1.6	13.5	1.5	15.1	1.4	16.6	1.3	18.3	1.3	19.7	1.2	21.1	1.1	22.5	1.1	23.8
2.8	1.7	15.1	1.6	16.7	1.5	18.4	1.4	20.2	1.4	21.8	1.3	23.3	1.2	24.8	1.2	26.2
3.0	1.8	16.7	1.7	18.5	1.6	20.3	1.5	22.2	1.5	23.9	1.4	25.5	1.3	27.1	1.3	28.7
3.2	1.9	18.4	1.8	20.3	1.7	22.2	1.6	24.2	1.6	26.1	1.5	27.8	1.4	29.5	1.4	31.2
3.4	2.0	20.2	1.9	22.2	1.8	24.2	1.7	26.3	1.7	28.3	1.6	30.2	1.5	32.0	1.5	33.8
3.6	2.1	22.0	2.0	24.2	1.9	26.3	1.8	28.5	1.8	30.6	1.7	32.7	1.6	34.6	1.6	36.5
3.8	2.2	23.9	2.1	26.2	2.0	28.5	1.9	30.8	1.9	33.0	1.8	35.2	1.7	37.3	1.7	39.3
4.0	2.3	25.8	2.2	28.3	2.1	30.7	2.0	33.1	2.0	35.5	1.9	37.8	1.8	40.0	1.8	42.2

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17.830.9

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
3:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

3% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.0	7.3	1.0	8.4	0.9	9.5	0.8	10.6	0.8	11.6	0.8	12.6	0.7	13.5	0.7	14.4
1.8	1.2	8.5	1.1	9.8	1.0	11.0	1.0	12.2	0.9	13.4	0.9	14.4	0.8	15.4	0.8	16.4
2.0	1.3	9.8	1.2	11.2	1.1	12.6	1.1	13.9	1.0	15.3	1.0	16.4	0.9	17.5	0.9	18.6
2.2	1.4	11.2	1.3	12.8	1.2	14.3	1.2	15.8	1.1	17.2	1.1	18.5	1.0	19.7	1.0	20.9
2.4	1.5	12.7	1.4	14.4	1.3	16.1	1.3	17.7	1.2	19.2	1.2	20.7	1.1	22.0	1.1	23.4
2.6	1.6	14.2	1.5	16.1	1.5	17.9	1.4	19.7	1.3	21.3	1.3	23.0	1.2	24.4	1.2	25.9
2.8	1.7	15.9	1.6	17.9	1.6	19.8	1.5	21.7	1.4	23.5	1.4	25.3	1.3	26.9	1.3	28.5
3.0	1.8	17.7	1.8	19.8	1.7	21.8	1.6	23.8	1.5	25.7	1.5	27.7	1.4	29.4	1.4	31.2
3.2	2.0	19.5	1.9	21.7	1.8	23.9	1.7	26.0	1.7	28.0	1.6	30.1	1.5	32.0	1.5	33.9
3.4	2.1	21.4	2.0	23.7	1.9	26.0	1.8	28.3	1.8	30.4	1.7	32.6	1.6	34.7	1.6	36.7
3.6	2.2	23.3	2.1	25.8	2.0	28.2	1.9	30.6	1.9	32.9	1.8	35.2	1.7	37.5	1.7	39.6
3.8	2.3	25.3	2.2	27.9	2.1	30.5	2.0	33.0	2.0	35.5	1.9	37.9	1.8	40.3	1.8	42.6
4.0	2.4	27.4	2.3	30.1	2.2	32.8	2.2	35.5	2.1	38.1	2.0	40.7	2.0	43.2	1.9	45.7

4% Land Slope

1.6	1.1	7.8	1.0	9.1	1.0	10.3	0.9	11.5	0.9	12.7	0.8	13.8	0.8	14.9	0.7	15.9
1.8	1.2	9.0	1.1	10.4	1.1	11.8	1.0	13.2	1.0	14.5	0.9	15.7	0.9	17.0	0.8	18.1
2.0	1.3	10.4	1.2	11.9	1.2	13.4	1.1	15.0	1.1	16.4	1.0	17.8	1.0	19.2	0.9	20.6
2.2	1.4	11.8	1.4	13.5	1.3	15.2	1.2	16.9	1.2	18.4	1.1	20.0	1.1	21.5	1.0	23.0
2.4	1.5	13.4	1.5	15.2	1.4	17.0	1.3	18.8	1.3	20.5	1.2	22.3	1.2	23.9	1.1	25.6
2.6	1.7	15.1	1.6	17.1	1.5	19.0	1.4	20.9	1.4	22.8	1.3	24.7	1.3	26.4	1.2	28.2
2.8	1.8	16.9	1.7	19.0	1.6	21.1	1.6	23.1	1.5	25.1	1.5	27.2	1.4	29.0	1.4	30.9
3.0	1.9	18.7	1.8	21.0	1.7	23.3	1.7	25.4	1.6	27.6	1.6	29.8	1.5	31.7	1.5	33.7
3.2	2.0	20.6	1.9	23.1	1.9	25.5	1.8	27.8	1.7	30.2	1.7	32.4	1.6	34.5	1.6	36.6
3.4	2.1	22.6	2.1	25.3	2.0	27.8	1.9	30.3	1.9	32.8	1.8	35.1	1.7	37.4	1.7	39.7
3.6	2.3	24.7	2.2	27.5	2.1	30.2	2.0	32.8	2.0	35.5	1.9	37.9	1.8	40.4	1.8	42.8
3.8	2.4	26.9	2.3	29.8	2.2	32.7	2.1	35.4	2.1	38.2	2.0	40.8	2.0	43.5	1.9	46.0
4.0	2.5	29.2	2.4	32.2	2.3	35.2	2.3	38.1	2.2	41.0	2.1	43.8	2.1	46.6	2.0	49.3

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17,830.10

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
3:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

5% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.1	8.4	1.1	9.9	1.0	11.3	1.0	12.6	0.9	13.9	0.9	15.2	0.9	16.5	0.8	17.8
1.8	1.2	9.8	1.2	11.4	1.1	13.0	1.1	14.5	1.0	16.0	1.0	17.5	1.0	18.9	0.9	20.3
2.0	1.4	11.3	1.3	13.1	1.2	14.8	1.2	16.5	1.1	18.2	1.1	19.8	1.1	21.4	1.0	22.9
2.2	1.5	12.9	1.4	14.9	1.3	16.7	1.3	18.6	1.3	20.4	1.2	22.2	1.2	23.9	1.1	25.6
2.4	1.6	14.6	1.5	16.7	1.5	18.7	1.4	20.8	1.4	22.7	1.3	24.6	1.3	26.5	1.2	28.3
2.6	1.7	16.4	1.6	18.6	1.6	20.8	1.6	23.0	1.5	25.1	1.4	27.1	1.4	29.1	1.3	31.1
2.8	1.9	18.3	1.8	20.6	1.7	23.0	1.7	25.3	1.6	27.5	1.5	29.7	1.5	31.9	1.5	34.0
3.0	2.0	20.2	1.9	22.7	1.8	25.3	1.8	27.7	1.7	30.1	1.6	32.5	1.6	34.8	1.6	37.0
3.2	2.1	22.2	2.0	24.9	2.0	27.6	1.9	30.2	1.8	32.8	1.8	35.3	1.7	37.8	1.7	40.1
3.4	2.2	24.3	2.1	27.2	2.1	30.0	2.0	32.8	1.9	35.5	1.9	38.2	1.8	40.7	1.8	43.3
3.6	2.4	26.5	2.3	29.5	2.2	32.5	2.1	35.5	2.1	38.3	2.0	41.2	1.9	43.9	1.9	46.6
3.8	2.5	28.8	2.4	31.9	2.3	35.1	2.2	38.3	2.2	41.2	2.1	44.2	2.1	47.1	2.0	50.0
4.0	2.6	31.2	2.5	34.4	2.4	37.8	2.4	41.1	2.3	44.2	2.2	47.3	2.2	50.4	2.1	53.4

6% Land Slope

1.6	1.2	9.1	1.1	10.7	1.1	12.2	1.0	13.8	1.0	15.3	0.9	16.8	0.9	18.3		
1.8	1.3	10.6	1.2	12.4	1.2	14.1	1.1	15.8	1.1	17.5	1.1	19.1	1.0	20.8		
2.0	1.4	12.2	1.4	14.2	1.3	16.1	1.3	17.9	1.2	19.8	1.2	21.5	1.1	23.4		
2.2	1.6	13.9	1.5	16.1	1.4	18.1	1.4	20.1	1.3	22.2	1.3	24.1	1.3	26.0		
2.4	1.7	15.7	1.6	18.1	1.5	20.2	1.5	22.4	1.5	24.6	1.4	26.7	1.4	28.7		
2.6	1.8	17.6	1.7	20.1	1.7	22.4	1.6	24.8	1.6	27.1	1.5	29.4	1.5	31.6		
2.8	1.9	19.6	1.9	22.2	1.8	24.7	1.7	27.3	1.7	29.7	1.6	32.2	1.6	34.5		
3.0	2.1	21.7	2.0	24.4	1.9	27.1	1.8	29.9	1.8	32.5	1.7	35.1	1.7	37.6		
3.2	2.2	23.8	2.1	26.7	2.0	29.6	2.0	32.6	1.9	35.3	1.8	38.0	1.8	40.7		
3.4	2.3	26.0	2.2	29.1	2.1	32.2	2.1	35.3	2.0	38.2	2.0	41.0	1.9	43.9		
3.6	2.5	28.4	2.4	31.6	2.3	34.9	2.2	38.1	2.1	41.2	2.1	44.2	2.0	47.2		
3.8	2.6	30.8	2.5	34.2	2.4	37.7	2.3	41.0	2.3	44.3	2.2	47.5	2.2	50.6		
4.0	2.7	33.3	2.6	36.9	2.5	40.5	2.5	44.0	2.4	47.5	2.3	50.9	2.3	54.1		

1/ - In Feet 2/ - In Square Feet Per Foot

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
3:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

7% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet													
	4'		6'		8'		10'		12'		14'		16'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.2	9.8	1.2	11.6	1.1	13.3	1.1	15.0	1.0	16.7	1.0	18.4	1.0	20.0
1.8	1.4	11.5	1.3	13.4	1.2	15.3	1.2	17.2	1.2	19.1	1.1	20.9	1.1	22.7
2.0	1.5	13.2	1.4	15.4	1.4	17.5	1.3	19.6	1.3	21.6	1.2	23.6	1.2	25.5
2.2	1.6	15.0	1.6	17.4	1.5	19.7	1.4	22.0	1.4	24.2	1.3	26.3	1.3	28.4
2.4	1.8	16.9	1.7	19.5	1.6	22.0	1.6	24.5	1.5	26.8	1.5	29.1	1.4	31.4
2.6	1.9	19.0	1.8	21.7	1.7	24.4	1.7	27.0	1.6	29.5	1.6	32.0	1.6	34.4
2.8	2.0	21.1	1.9	24.0	1.9	26.8	1.8	29.6	1.8	32.3	1.7	34.9	1.7	37.5
3.0	2.1	23.3	2.1	26.4	2.0	29.4	1.9	32.3	1.9	35.2	1.8	38.0	1.8	40.7
3.2	2.3	25.5	2.2	28.8	2.1	32.0	2.1	35.1	2.0	38.1	1.9	41.1	1.9	44.0
3.4	2.4	27.9	2.3	31.3	2.2	34.7	2.2	38.0	2.1	41.2	2.1	44.3	2.0	47.4
3.6	2.5	30.3	2.4	34.9	2.4	37.5	2.3	41.0	2.2	44.4	2.2	47.7	2.1	50.9
3.8	2.7	32.8	2.6	36.7	2.5	40.4	2.4	44.1	2.4	47.7	2.3	51.2	2.3	54.6
4.0	2.8	35.5	2.7	39.5	2.6	43.4	2.5	47.2	2.5	51.0	2.4	54.7	2.4	58.4

8% Land Slope

1.6	1.3	10.5	1.2	12.5	1.2	14.4	1.1	16.3	1.1	18.1	1.1	20.0
1.8	1.4	12.2	1.4	14.4	1.3	16.5	1.3	18.6	1.2	20.6	1.2	22.6
2.0	1.6	14.0	1.5	16.4	1.4	18.7	1.4	21.0	1.3	23.2	1.3	25.4
2.2	1.7	15.9	1.6	18.5	1.6	21.0	1.5	23.5	1.5	25.9	1.4	28.3
2.4	1.8	17.9	1.8	20.7	1.7	23.4	1.6	26.1	1.6	28.7	1.5	31.3
2.6	2.0	20.0	1.9	23.0	1.8	25.9	1.8	28.8	1.7	31.6	1.6	34.4
2.8	2.1	22.2	2.0	25.4	1.9	28.5	1.9	31.6	1.8	34.6	1.8	37.6
3.0	2.2	24.6	2.1	27.9	2.1	31.2	2.0	34.5	2.0	37.7	1.9	40.9
3.2	2.3	27.1	2.3	30.6	2.2	34.0	2.1	37.5	2.1	40.9	2.0	44.3
3.4	2.5	29.7	2.4	33.3	2.3	37.0	2.3	40.6	2.2	44.2	2.1	47.8
3.6	2.6	32.4	2.5	36.2	2.4	40.1	2.4	43.9	2.3	47.6	2.3	51.3
3.8	2.7	35.1	2.7	39.2	2.6	43.2	2.5	47.2	2.5	51.1	2.4	54.9
4.0	2.9	37.9	2.8	42.2	2.7	46.4	2.6	50.6	2.6	54.7	2.5	58.7

1/ - In Feet 2/ In Square Feet Per Foot

5,L-17,830.12

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
3:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

9% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet											
	4'		6'		8'		10'		12'		14'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.3	11.2	1.3	13.4	1.2	15.5	1.2	17.6	1.1	19.7	1.1	21.7
1.8	1.5	13.1	1.4	15.5	1.4	17.8	1.3	20.2	1.3	22.5	1.2	24.7
2.0	1.6	15.1	1.5	17.7	1.5	20.3	1.5	22.8	1.4	25.3	1.4	27.8
2.2	1.7	17.1	1.7	20.0	1.6	22.8	1.6	25.6	1.5	28.3	1.5	31.0
2.4	1.9	19.3	1.8	22.4	1.8	25.4	1.7	28.4	1.7	31.3	1.6	34.2
2.6	2.0	21.6	1.9	24.9	1.9	28.1	1.8	31.3	1.8	34.4	1.7	37.5
2.8	2.1	23.9	2.1	27.5	2.0	30.9	2.0	34.2	1.9	37.5	1.9	40.9
3.0	2.3	26.4	2.2	30.2	2.1	33.7	2.1	37.3	2.0	40.8	2.0	44.3
3.2	2.4	29.0	2.3	32.9	2.3	36.7	2.2	40.4	2.2	44.1	2.1	47.8
3.4	2.5	31.7	2.5	35.7	2.4	39.7	2.3	43.7	2.3	47.6	2.2	51.4
3.6	2.7	34.5	2.6	38.7	2.5	42.9	2.5	47.0	2.4	51.1	2.4	55.1
3.8	2.8	37.4	2.7	41.7	2.6	46.2	2.6	50.5	2.5	54.8	2.5	59.0
4.0	2.9	40.4	2.9	44.9	2.8	49.5	2.7	54.1	2.7	58.6	2.6	62.9

10% Land Slope

1.6	1.4	12.0	1.3	14.4	1.3	16.8	1.2	19.2	1.2	21.4
1.8	1.5	14.0	1.5	16.7	1.4	19.3	1.4	21.9	1.3	24.3
2.0	1.7	16.2	1.6	19.1	1.5	21.9	1.5	24.7	1.5	27.3
2.2	1.8	18.5	1.7	21.6	1.7	24.6	1.6	27.6	1.6	30.4
2.4	1.9	20.9	1.9	24.2	1.8	27.4	1.8	30.6	1.7	33.6
2.6	2.1	23.4	2.0	26.9	2.0	30.3	1.9	33.7	1.9	36.9
2.8	2.2	25.9	2.1	29.6	2.1	33.3	2.0	36.9	2.0	40.3
3.0	2.3	28.5	2.3	32.4	2.2	36.3	2.2	40.2	2.1	43.7
3.2	2.5	31.2	2.4	35.3	2.4	39.4	2.3	43.5	2.2	47.3
3.4	2.6	34.0	2.5	38.3	2.5	42.6	2.4	46.9	2.4	51.0
3.6	2.7	36.9	2.7	41.4	2.6	45.9	2.6	50.4	2.5	54.8
3.8	2.9	39.9	2.8	44.6	2.8	49.3	2.7	54.0	2.6	58.6
4.0	3.0	43.1	2.9	47.9	2.9	52.8	2.8	57.7	2.8	62.5

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17,830.13

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
3:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

11% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet									
	4'		6'		8'		10'		12'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.4	12.9	1.3	15.5	1.3	18.2	1.3	20.8	1.2	23.3
1.8	1.5	15.1	1.4	17.9	1.4	20.9	1.4	23.7	1.3	26.5
2.0	1.7	17.4	1.6	20.5	1.6	23.7	1.5	26.7	1.5	29.8
2.2	1.8	19.8	1.8	23.2	1.7	26.6	1.7	29.8	1.6	33.1
2.4	2.0	22.3	1.9	25.9	1.9	29.5	1.8	33.0	1.8	36.5
2.6	2.1	24.9	2.0	28.7	2.0	32.5	1.9	36.3	1.9	40.0
2.8	2.3	27.6	2.2	31.6	2.2	35.6	2.1	39.6	2.0	43.5
3.0	2.4	30.4	2.3	34.6	2.3	38.8	2.2	43.0	2.2	47.1
3.2	2.5	33.3	2.5	37.7	2.4	42.1	2.4	46.5	2.3	50.8
3.4	2.7	36.3	2.6	40.9	2.6	45.5	2.5	50.1	2.5	54.6
3.6	2.8	39.4	2.7	44.2	2.7	49.0	2.7	53.8	2.6	58.5
3.8	2.9	42.7	2.9	47.6	2.8	52.6	2.8	57.6	2.7	62.5
4.0	3.1	46.1	3.0	51.1	2.9	56.3	2.9	61.5	2.8	66.6

12% Land Slope

1.6	1.4	13.9	1.4	16.8	1.4	19.8	1.3	22.5
1.8	1.6	16.2	1.5	19.3	1.5	22.6	1.5	25.6
2.0	1.7	18.6	1.7	22.0	1.6	25.5	1.6	28.8
2.2	1.9	21.1	1.8	24.8	1.8	28.5	1.7	32.1
2.4	2.0	23.8	2.0	27.7	1.9	31.6	1.9	35.5
2.6	2.2	26.6	2.1	30.7	2.0	34.8	2.0	39.0
2.8	2.3	29.5	2.3	33.8	2.2	38.1	2.2	42.6
3.0	2.4	32.5	2.4	37.0	2.3	41.5	2.3	46.3
3.2	2.6	35.6	2.5	40.3	2.5	45.1	2.5	50.0
3.4	2.7	38.9	2.7	43.8	2.6	48.8	2.6	53.8
3.6	2.9	42.3	2.8	47.4	2.8	52.6	2.7	57.7
3.8	3.0	45.8	3.0	51.1	2.9	56.5	2.9	61.7
4.0	3.2	49.4	3.1	54.9	3.0	60.5	3.0	65.8

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17.830.14

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
3:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

Channel Bottom Width - Feet

Total Height of Diversion Above Channel	13% Land Slope								14% Land Slope					
	4'		6'		8'		10'		4'		6'		8'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.5	15.0	1.4	18.2	1.4	21.4	1.4	24.6	1.5	16.2	1.5	19.7	1.5	23.1
1.8	1.6	17.5	1.6	21.0	1.5	24.4	1.5	27.8	1.7	18.8	1.6	22.6	1.6	26.3
2.0	1.8	20.1	1.7	23.8	1.7	27.5	1.6	31.1	1.8	21.5	1.8	25.6	1.8	29.6
2.2	1.9	22.8	1.9	26.8	1.8	30.7	1.8	34.5	2.0	24.3	1.9	28.7	1.9	33.0
2.4	2.1	25.6	2.0	29.8	2.0	34.0	1.9	38.0	2.1	27.3	2.1	32.0	2.0	36.6
2.6	2.2	28.5	2.2	33.0	2.1	37.4	2.1	41.6	2.3	30.5	2.2	35.4	2.2	40.3
2.8	2.3	31.5	2.3	36.2	2.2	40.9	2.2	45.4	2.4	33.9	2.3	39.0	2.3	44.1
3.0	2.5	34.7	2.4	39.6	2.4	44.5	2.3	49.3	2.6	37.4	2.5	42.8	2.5	48.1
3.2	2.6	38.0	2.6	43.2	2.5	48.3	2.5	53.4	2.7	41.1	2.6	46.7	2.6	52.2
3.4	2.8	41.5	2.7	46.9	2.7	52.3	2.6	57.6	2.8	45.0	2.8	50.7	2.8	56.4
3.6	2.9	45.2	2.8	50.8	2.8	56.4	2.7	61.9	3.0	49.0	2.9	54.9	2.9	60.8
3.8	3.0	49.1	3.0	54.9	2.9	60.6	2.9	66.3	3.1	53.2	3.1	59.3	3.0	65.3
4.0	3.2	53.1	3.1	59.0	3.1	64.9	3.0	70.8	3.3	57.6	3.2	63.8	3.2	70.0

	15% Land Slope								16% Land Slope					
1.6	1.5	17.5	1.5	21.3	1.5	25.1			1.6	19.0	1.6	23.2	1.6	27.3
1.8	1.7	20.3	1.7	24.4	1.7	28.5			1.8	21.9	1.7	26.4	1.7	30.8
2.0	1.9	23.2	1.8	27.6	1.8	32.0			1.9	25.0	1.9	29.8	1.9	34.5
2.2	2.0	26.3	2.0	31.0	2.0	35.6			2.1	28.3	2.0	33.4	2.0	38.4
2.4	2.2	29.5	2.1	34.5	2.1	39.4			2.2	31.8	2.2	37.2	2.2	42.5
2.6	2.3	32.9	2.3	38.2	2.2	43.4			2.4	35.5	2.3	41.2	2.3	46.8
2.8	2.5	36.5	2.4	42.0	2.4	47.5			2.6	39.4	2.5	45.4	2.5	51.3
3.0	2.6	40.3	2.6	46.1	2.6	51.8			2.7	43.5	2.6	49.8	2.7	56.0
3.2	2.7	44.3	2.7	50.3	2.7	56.3			2.8	47.8	2.8	54.4	2.8	60.9
3.4	2.9	48.5	2.9	54.7	2.9	60.9			3.0	52.3	2.9	59.2	3.0	66.0
3.6	3.1	52.9	3.0	59.3	3.0	65.7			3.1	57.0	3.1	64.2	3.1	71.3

1/ - In Feet 2/ - In Square Feet Per Foot

S.L-17,830.15

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
4:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

1% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.0	7.3	0.9	8.2	0.8	9.0	0.8	9.8	0.7	10.6	0.7	11.4	0.7	12.1	0.6	12.8
1.8	1.1	8.6	1.0	9.6	0.9	10.6	0.9	11.6	0.8	12.5	0.8	13.4	0.7	14.2	0.7	15.0
2.0	1.2	10.0	1.1	11.2	1.0	12.3	1.0	13.5	0.9	14.5	0.9	15.5	0.8	16.4	0.8	17.3
2.2	1.3	11.5	1.2	12.9	1.1	14.1	1.1	15.4	1.0	16.6	1.0	17.7	0.9	18.7	0.9	19.7
2.4	1.4	13.1	1.3	14.7	1.2	16.0	1.2	17.4	1.1	18.8	1.1	20.0	1.0	21.1	1.0	22.2
2.6	1.5	14.9	1.4	16.5	1.4	18.0	1.3	19.5	1.2	21.0	1.2	22.4	1.1	23.6	1.1	24.8
2.8	1.6	16.7	1.5	18.4	1.5	20.1	1.4	21.7	1.3	23.3	1.3	24.8	1.2	26.2	1.2	27.5
3.0	1.7	18.6	1.6	20.4	1.6	22.3	1.5	24.0	1.4	25.7	1.4	27.3	1.3	28.8	1.3	30.3
3.2	1.8	20.6	1.8	22.5	1.7	24.6	1.6	26.4	1.6	28.2	1.5	29.9	1.4	31.6	1.4	33.2
3.4	1.9	22.8	1.9	24.7	1.8	26.9	1.7	28.8	1.7	30.8	1.6	32.6	1.6	34.5	1.5	36.2
3.6	2.1	25.0	2.0	27.1	1.9	29.3	1.8	31.3	1.8	33.5	1.7	35.4	1.7	37.4	1.6	39.3
3.8	2.2	27.3	2.1	29.5	2.0	31.8	1.9	34.0	1.9	36.2	1.8	38.3	1.8	40.4	1.7	42.4
4.0	2.3	29.7	2.2	32.1	2.1	34.5	2.0	36.8	2.0	39.1	1.9	41.3	1.9	43.5	1.8	45.6

2% Land Slope

1.6	1.0	8.0	0.9	9.1	0.9	10.1	0.8	11.0	0.8	11.9	0.8	12.8	0.7	13.7	0.7	14.5
1.8	1.1	9.4	1.0	10.6	1.0	11.8	0.9	12.9	0.9	13.9	0.9	14.9	0.8	15.9	0.8	16.8
2.0	1.2	10.9	1.2	12.3	1.1	13.6	1.0	14.9	1.0	16.0	1.0	17.2	0.9	18.3	0.9	19.3
2.2	1.4	12.6	1.3	14.1	1.2	15.5	1.2	16.9	1.1	18.2	1.1	19.5	1.0	20.8	1.0	21.9
2.4	1.5	14.4	1.4	16.0	1.3	17.6	1.3	19.0	1.2	20.5	1.2	22.0	1.1	23.3	1.1	24.6
2.6	1.6	16.2	1.5	18.0	1.4	19.7	1.4	21.3	1.3	22.9	1.3	24.6	1.2	26.0	1.2	27.4
2.8	1.7	18.2	1.6	20.1	1.5	21.9	1.5	23.7	1.4	25.4	1.4	27.2	1.3	28.8	1.3	30.3
3.0	1.8	20.3	1.7	22.3	1.7	24.2	1.6	26.2	1.5	28.0	1.5	29.9	1.4	31.6	1.4	33.3
3.2	1.9	22.4	1.8	24.6	1.8	26.6	1.7	28.7	1.6	30.7	1.6	32.7	1.6	34.5	1.5	36.4
3.4	2.0	24.7	1.9	27.0	1.9	29.1	1.8	31.4	1.8	33.5	1.7	35.6	1.7	37.6	1.6	39.6
3.6	2.1	27.1	2.1	29.5	2.0	31.7	1.9	34.2	1.9	36.5	1.8	38.7	1.8	40.8	1.7	43.0
3.8	2.3	29.5	2.2	32.1	2.1	34.5	2.0	37.1	2.0	39.5	1.9	41.9	1.9	44.1	1.8	46.4
4.0	2.4	32.1	2.3	34.8	2.2	37.5	2.1	40.1	2.1	42.6	2.0	45.1	2.0	47.5	2.0	49.9

1/ - In Feet 2/ - In Square Feet Per Foot

5,L-17,830.16

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
4:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

3% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.1	8.7	1.0	9.9	0.9	11.1	0.9	12.2	0.9	13.3	0.8	14.4	0.8	15.4	0.7	16.4
1.8	1.2	10.3	1.1	11.6	1.1	13.0	1.0	14.2	1.0	15.4	0.9	16.6	0.9	17.8	0.9	18.9
2.0	1.3	12.0	1.2	13.4	1.2	15.0	1.1	16.3	1.1	17.7	1.0	19.0	1.0	20.4	1.0	21.6
2.2	1.4	13.8	1.3	15.3	1.3	17.0	1.2	18.5	1.2	20.0	1.1	21.5	1.1	23.0	1.1	24.4
2.4	1.5	15.7	1.5	17.4	1.4	19.2	1.3	20.8	1.3	22.5	1.3	24.1	1.2	25.7	1.2	27.3
2.6	1.7	17.7	1.6	19.6	1.5	21.5	1.5	23.3	1.4	25.1	1.4	26.9	1.3	28.6	1.3	30.3
2.8	1.8	19.8	1.7	21.9	1.6	23.9	1.6	25.8	1.5	27.8	1.5	29.7	1.4	31.6	1.4	33.4
3.0	1.9	22.0	1.8	24.3	1.7	26.4	1.7	28.4	1.6	30.6	1.6	32.7	1.6	34.7	1.5	36.7
3.2	2.0	24.3	1.9	26.7	1.9	29.1	1.8	31.3	1.7	33.6	1.7	35.8	1.7	37.9	1.6	40.0
3.4	2.1	26.7	2.1	29.2	2.0	31.8	1.9	34.2	1.9	36.6	1.8	38.9	1.8	41.2	1.7	43.5
3.6	2.2	29.3	2.2	31.9	2.1	34.6	2.0	37.2	2.0	39.7	1.9	42.2	1.9	44.6	1.8	47.1
3.8	2.4	32.0	2.3	34.7	2.2	37.5	2.1	40.3	2.1	43.0	2.0	45.6	2.0	48.2	1.9	50.8
4.0	2.5	34.8	2.4	37.7	2.3	40.6	2.3	43.5	2.2	46.4	2.1	49.1	2.1	51.9	2.0	54.6

4% Land Slope

1.6	1.1	9.5	1.1	11.0	1.0	12.4	1.0	13.7	0.9	15.0	0.9	16.2	0.8	17.5	0.8	18.7
1.8	1.2	11.3	1.2	12.8	1.1	14.4	1.1	15.9	1.0	17.3	1.0	18.7	1.0	20.0	0.9	21.3
2.0	1.4	13.1	1.3	14.8	1.3	16.5	1.2	18.2	1.2	19.8	1.1	21.3	1.1	22.8	1.0	24.2
2.2	1.5	15.0	1.4	16.9	1.4	18.7	1.3	20.6	1.3	22.3	1.2	24.0	1.2	25.6	1.2	27.2
2.4	1.6	17.1	1.5	19.1	1.5	21.1	1.4	23.1	1.4	25.0	1.3	26.8	1.3	28.6	1.3	30.3
2.6	1.7	19.2	1.7	21.4	1.6	23.6	1.5	25.7	1.5	27.8	1.5	29.8	1.4	31.7	1.4	33.6
2.8	1.9	21.5	1.8	23.8	1.7	26.2	1.7	28.4	1.6	30.7	1.6	32.8	1.5	34.9	1.5	36.9
3.0	2.0	23.9	1.9	26.4	1.9	28.9	1.8	31.3	1.7	33.7	1.7	36.0	1.6	38.3	1.6	40.4
3.2	2.1	26.5	2.0	29.1	2.0	31.8	1.9	34.3	1.8	36.8	1.8	39.3	1.8	41.7	1.7	44.1
3.4	2.2	29.1	2.1	31.9	2.1	34.7	2.0	37.4	2.0	40.1	1.9	42.8	1.9	45.3	1.8	47.9
3.6	2.3	31.9	2.3	34.8	2.2	37.8	2.1	40.7	2.1	43.5	2.0	46.3	2.0	49.1	2.0	51.8
3.8	2.5	34.8	2.4	37.8	2.3	40.9	2.3	44.0	2.2	47.0	2.2	50.0	2.1	52.9	2.1	55.9
4.0	2.6	37.8	2.5	41.0	2.4	44.2	2.4	47.4	2.3	50.7	2.3	53.8	2.2	56.9	2.2	60.0

1/ - In Feet 2/ - In Square Feet Per Foot

5,L-17,830.17

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
4:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

5% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet													
	4'		6'		8'		10'		12'		14'		16'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.2	10.4	1.1	12.1	1.1	13.8	1.0	15.4	1.0	17.0	1.0	18.5	0.9	20.0
1.8	1.3	12.3	1.2	14.2	1.2	15.9	1.2	17.7	1.1	19.4	1.1	21.1	1.0	22.7
2.0	1.4	14.4	1.4	16.4	1.3	18.2	1.3	20.2	1.2	22.0	1.2	23.9	1.2	25.6
2.2	1.6	16.5	1.5	18.6	1.4	20.6	1.4	22.7	1.4	24.7	1.3	26.8	1.2	28.7
2.4	1.7	18.7	1.6	21.0	1.6	23.2	1.5	25.4	1.5	27.6	1.4	29.8	1.4	31.9
2.6	1.8	21.0	1.8	23.5	1.7	25.9	1.6	28.3	1.6	30.7	1.6	33.0	1.5	35.3
2.8	1.9	23.4	1.9	26.1	1.8	28.7	1.8	31.3	1.7	33.9	1.7	36.4	1.6	38.8
3.0	2.1	26.0	2.0	28.9	1.9	31.6	1.9	34.4	1.8	37.2	1.8	39.8	1.8	42.4
3.2	2.2	28.8	2.1	31.8	2.1	34.7	2.0	37.7	1.9	40.6	1.9	43.4	1.9	46.1
3.4	2.3	31.7	2.2	34.9	2.2	38.0	2.1	41.1	2.1	44.2	2.0	47.1	2.0	50.0
3.6	2.4	34.7	2.4	38.0	2.3	41.4	2.2	44.6	2.2	47.8	2.1	50.9	2.1	54.0
3.8	2.6	37.8	2.5	41.3	2.4	44.8	2.4	48.2	2.3	51.6	2.3	54.9	2.2	58.2
4.0	2.7	41.1	2.6	44.8	2.6	48.4	2.5	52.0	2.4	55.5	2.4	59.0	2.4	62.4

6% Land Slope

1.6	1.2	11.3	1.2	13.4	1.1	15.3	1.1	17.3	1.1	19.2	1.0	21.1	1.0	22.9
1.8	1.3	13.4	1.3	15.6	1.3	17.7	1.2	19.9	1.2	22.0	1.2	24.1	1.1	26.1
2.0	1.5	15.6	1.4	18.0	1.4	20.3	1.4	22.6	1.3	24.9	1.3	27.2	1.2	29.4
2.2	1.6	17.8	1.6	20.4	1.5	23.0	1.5	25.5	1.4	28.0	1.4	30.4	1.4	32.8
2.4	1.7	20.2	1.7	23.0	1.7	25.8	1.6	28.6	1.6	31.3	1.5	33.8	1.5	36.4
2.6	1.9	22.8	1.8	25.8	1.8	28.8	1.7	31.7	1.7	34.6	1.6	37.4	1.6	40.2
2.8	2.0	25.6	2.0	28.8	1.9	31.9	1.9	35.0	1.8	38.0	1.8	41.0	1.7	44.0
3.0	2.1	28.4	2.1	31.8	2.0	35.1	2.0	38.4	1.9	41.6	1.9	44.8	1.8	48.0
3.2	2.3	31.4	2.2	35.0	2.2	38.5	2.1	42.0	2.1	45.4	2.0	48.8	2.0	52.1
3.4	2.4	34.6	2.3	38.3	2.3	42.0	2.2	45.7	2.2	49.3	2.1	52.9	2.1	56.4
3.6	2.5	37.9	2.5	41.8	2.4	45.7	2.4	49.6	2.3	53.4	2.3	57.2	2.2	60.9
3.8	2.7	41.2	2.6	45.4	2.5	49.5	2.5	53.6	2.4	57.6	2.4	61.6	2.3	65.5
4.0	2.8	44.7	2.7	49.1	2.7	53.4	2.6	57.7	2.6	61.9	2.5	66.1	2.5	70.3

1/ - In Feet 2/ - In Square Feet Per Foot

5,L-17,830.18

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
4:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

7% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet											
	4'		6'		8'		10'		12'		14'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.3	12.3	1.2	14.5	1.2	16.6	1.2	18.7	1.1	20.8	1.1	22.8
1.8	1.4	14.5	1.4	16.9	1.3	19.3	1.3	21.6	1.3	23.9	1.2	26.1
2.0	1.5	16.9	1.5	19.5	1.5	22.2	1.4	24.7	1.4	27.1	1.4	29.5
2.2	1.7	19.4	1.6	22.3	1.6	25.1	1.6	27.8	1.5	30.4	1.5	33.0
2.4	1.8	22.0	1.8	25.1	1.7	28.2	1.7	31.0	1.7	33.8	1.6	36.6
2.6	1.9	24.8	1.9	28.1	1.9	31.4	1.8	34.4	1.8	37.4	1.7	40.4
2.8	2.1	27.8	2.0	31.3	2.0	34.7	2.0	38.0	1.9	41.2	1.9	44.4
3.0	2.2	31.0	2.1	34.6	2.1	38.2	2.1	41.7	2.0	45.1	2.0	48.5
3.2	2.4	34.3	2.3	38.1	2.3	41.9	2.2	45.5	2.2	49.2	2.1	52.8
3.4	2.5	37.7	2.4	41.7	2.4	45.7	2.3	49.5	2.3	53.4	2.3	57.2
3.6	2.6	41.2	2.6	45.5	2.5	49.6	2.5	53.7	2.4	57.8	2.4	61.8
3.8	2.8	44.9	2.7	49.3	2.7	53.7	2.6	58.0	2.6	62.3	2.5	66.5
4.0	2.9	48.7	2.8	53.3	2.8	57.9	2.7	62.4	2.7	66.9	2.6	71.3

8% Land Slope

1.6	1.3	13.4	1.3	16.0	1.3	18.5	1.2	21.0	1.2	23.4	1.2	25.8
1.8	1.4	15.8	1.4	18.6	1.4	21.4	1.3	24.1	1.3	26.8	1.3	29.4
2.0	1.6	18.3	1.6	21.4	1.5	24.5	1.5	27.4	1.5	30.3	1.4	33.1
2.2	1.7	21.0	1.7	24.4	1.7	27.7	1.6	30.8	1.6	33.9	1.6	36.9
2.4	1.9	23.9	1.8	27.5	1.8	31.1	1.8	34.4	1.7	37.7	1.7	40.9
2.6	2.0	27.0	2.0	30.8	2.0	34.6	1.9	38.1	1.9	41.6	1.8	45.0
2.8	2.2	30.3	2.1	34.2	2.1	38.2	2.0	41.9	2.0	45.6	2.0	49.3
3.0	2.3	33.7	2.3	37.8	2.2	41.9	2.2	45.9	2.1	49.8	2.1	53.7
3.2	2.4	37.3	2.4	41.6	2.4	45.8	2.3	50.1	2.3	54.2	2.2	58.3
3.4	2.6	41.0	2.5	45.5	2.5	49.9	2.5	54.4	2.4	58.8	2.4	63.1
3.6	2.7	44.9	2.7	49.6	2.6	54.2	2.6	58.9	2.5	63.5	2.5	68.0
3.8	2.9	48.9	2.8	53.8	2.8	58.7	2.7	63.6	2.7	68.4	2.6	73.1
4.0	3.0	53.0	3.0	58.2	2.9	63.3	2.9	68.4	2.8	73.4	2.8	78.4

1/ - In Feet 2/ - In Square Feet Per Foot

5.L-17,830.19

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
6:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

1% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.0	9.3	0.9	10.3	0.9	11.2	0.8	12.1	0.8	12.9	0.8	13.7	0.7	14.5	0.7	15.3
1.8	1.1	11.4	1.0	12.4	1.0	13.4	0.9	14.4	0.9	15.3	0.9	16.2	0.8	17.0	0.8	17.9
2.0	1.2	13.6	1.1	14.6	1.1	15.7	1.0	16.8	1.0	17.8	1.0	18.8	0.9	19.7	0.9	20.7
2.2	1.3	15.9	1.2	17.0	1.2	18.2	1.1	19.3	1.1	20.4	1.1	21.5	1.0	22.6	1.0	23.6
2.4	1.4	18.3	1.3	19.5	1.3	20.8	1.2	22.0	1.2	23.2	1.2	24.4	1.1	25.6	1.1	26.7
2.6	1.5	20.8	1.4	22.1	1.4	23.5	1.3	24.8	1.3	26.1	1.3	27.4	1.2	28.7	1.2	29.9
2.8	1.6	23.4	1.6	24.8	1.5	26.3	1.5	27.7	1.4	29.1	1.4	30.6	1.3	32.0	1.3	33.3
3.0	1.7	26.0	1.7	27.6	1.6	29.2	1.6	30.7	1.5	32.3	1.5	33.9	1.4	35.4	1.4	36.8
3.2	1.8	28.7	1.8	30.5	1.7	32.2	1.7	33.8	1.6	35.6	1.6	37.3	1.5	38.9	1.5	40.4
3.4	2.0	31.5	1.9	33.5	1.8	35.3	1.8	37.1	1.7	39.0	1.7	40.8	1.7	42.5	1.6	44.1
3.6	2.1	34.4	2.0	36.6	1.9	38.5	1.9	40.5	1.9	42.5	1.8	44.4	1.8	46.2	1.7	47.9
3.8	2.2	37.4	2.1	39.6	2.1	41.8	2.0	44.0	2.0	46.1	1.9	48.1	1.9	50.1	1.8	51.9
4.0	2.3	40.6	2.2	43.0	2.2	45.3	2.1	47.6	2.1	49.8	2.0	52.0	2.0	54.1	1.9	56.0

2% Land Slope

1.6	1.0	10.5	1.0	11.7	0.9	12.8	0.9	13.9	0.9	15.0	0.8	16.0	0.8	17.0	0.8	18.0
1.8	1.1	12.7	1.1	14.0	1.1	15.2	1.0	16.4	1.0	17.6	0.9	18.8	0.9	19.9	0.9	21.0
2.0	1.3	14.9	1.2	16.4	1.2	17.7	1.1	19.1	1.1	20.4	1.1	21.7	1.0	23.0	1.0	24.2
2.2	1.4	17.2	1.3	18.9	1.3	20.4	1.2	21.9	1.2	23.4	1.2	24.8	1.1	26.2	1.1	27.6
2.4	1.5	19.7	1.4	21.5	1.4	23.2	1.3	24.9	1.3	26.5	1.3	28.1	1.3	29.6	1.2	31.1
2.6	1.6	22.5	1.6	24.4	1.5	26.2	1.5	28.1	1.4	29.8	1.4	31.5	1.4	33.2	1.3	34.8
2.8	1.7	25.4	1.7	27.4	1.6	29.4	1.6	31.4	1.5	33.3	1.5	35.1	1.5	36.9	1.4	38.7
3.0	1.9	28.5	1.8	30.6	1.7	32.7	1.7	34.8	1.7	36.9	1.6	38.9	1.6	40.8	1.5	42.7
3.2	2.0	31.7	1.9	34.0	1.8	36.2	1.8	38.4	1.8	40.6	1.7	42.7	1.7	44.8	1.7	46.9
3.4	2.1	35.1	2.0	37.5	2.0	39.8	1.9	42.1	1.9	44.4	1.8	46.7	1.8	48.9	1.8	51.1
3.6	2.2	38.6	2.1	41.1	2.1	43.5	2.0	46.0	2.0	48.4	2.0	50.8	1.9	53.1	1.9	55.4
3.8	2.3	42.2	2.3	44.8	2.2	47.4	2.2	50.0	2.1	52.5	2.1	55.1	2.0	57.5	2.0	59.9
4.0	2.5	45.9	2.4	48.7	2.3	51.4	2.3	54.1	2.2	56.9	2.2	59.5	2.1	62.0	2.1	64.5

1/ - In Feet 2/ - In Square Feet Per Foot

CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
6:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

3% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet															
	4'		6'		8'		10'		12'		14'		16'		18'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.1	11.9	1.1	13.4	1.0	14.7	1.0	16.1	1.0	17.4	0.9	18.7	0.9	20.0	0.9	21.2
1.8	1.2	14.1	1.2	15.7	1.1	17.3	1.1	18.9	1.1	20.4	1.0	21.9	1.0	23.3	1.0	24.7
2.0	1.3	16.5	1.3	18.3	1.3	20.1	1.2	21.9	1.2	23.6	1.1	25.2	1.1	26.8	1.1	28.4
2.2	1.5	19.1	1.4	21.1	1.4	23.1	1.3	25.0	1.3	26.9	1.3	28.7	1.3	30.5	1.2	32.3
2.4	1.6	21.9	1.5	24.1	1.5	26.2	1.5	28.3	1.4	30.4	1.4	32.4	1.4	34.4	1.3	36.4
2.6	1.7	24.9	1.7	27.3	1.6	29.6	1.6	31.9	1.5	34.1	1.5	36.3	1.5	38.5	1.4	40.6
2.8	1.8	28.2	1.8	30.7	1.7	33.2	1.7	35.6	1.7	38.0	1.6	40.4	1.6	42.7	1.6	45.0
3.0	2.0	31.7	1.9	34.4	1.9	37.0	1.8	39.6	1.8	42.1	1.7	44.6	1.7	47.1	1.7	49.5
3.2	2.1	35.4	2.0	38.2	2.0	41.0	1.9	43.7	1.9	46.4	1.9	49.1	1.8	51.7	1.8	54.3
3.4	2.2	39.3	2.2	42.3	2.1	45.2	2.1	48.0	2.0	50.9	2.0	53.7	2.0	56.5	1.9	59.2
3.6	2.4	43.4	2.3	46.5	2.2	49.5	2.2	52.5	2.2	55.5	2.1	58.5	2.1	61.4	2.1	64.3
3.8	2.5	47.6	2.4	50.8	2.4	54.0	2.3	57.2	2.3	60.3	2.2	63.4	2.2	66.5	2.2	69.5
4.0	2.6	52.1	2.6	55.4	2.5	58.7	2.5	62.0	2.4	65.3	2.4	68.5	2.3	71.8	2.3	75.0

4% Land Slope

1.6	1.2	13.5	1.1	15.2	1.1	16.8	1.1	18.5	1.0	20.1	1.0	21.7	1.0	23.3
1.8	1.3	16.2	1.3	18.1	1.2	19.9	1.2	21.8	1.2	23.6	1.1	25.4	1.1	27.2
2.0	1.4	19.1	1.4	21.2	1.3	23.2	1.3	25.3	1.3	27.3	1.2	29.3	1.2	31.3
2.2	1.6	22.2	1.5	24.5	1.5	26.8	1.4	29.0	1.4	31.2	1.4	33.4	1.4	35.5
2.4	1.7	25.5	1.7	28.0	1.6	30.5	1.6	32.9	1.5	35.3	1.5	37.7	1.5	40.0
2.6	1.8	28.9	1.8	31.6	1.7	34.3	1.7	37.0	1.7	39.6	1.6	42.1	1.6	44.6
2.8	2.0	32.6	1.9	35.5	1.9	38.4	1.8	41.2	1.8	44.0	1.8	46.8	1.7	49.5
3.0	2.1	36.5	2.0	39.6	2.0	42.7	2.0	45.7	1.9	48.7	1.9	51.6	1.9	54.5
3.2	2.2	40.6	2.2	43.9	2.1	47.2	2.1	50.3	2.0	53.6	2.0	56.7	2.0	59.8
3.4	2.4	44.9	2.3	48.4	2.3	51.8	2.2	55.1	2.2	58.5	2.1	61.8	2.1	65.1
3.6	2.5	49.4	2.5	53.0	2.4	56.6	2.3	60.2	2.3	63.7	2.3	67.2	2.3	70.7
3.8	2.6	54.1	2.6	57.9	2.5	61.6	2.5	65.4	2.4	69.1	2.4	72.8	2.4	76.4
4.0	2.8	59.0	2.7	63.0	2.7	66.9	2.6	70.8	2.6	74.6	2.5	78.5	2.5	82.4

1/ - In Feet 2/ - In Square Feet Per Foot

5,L-17,830.21

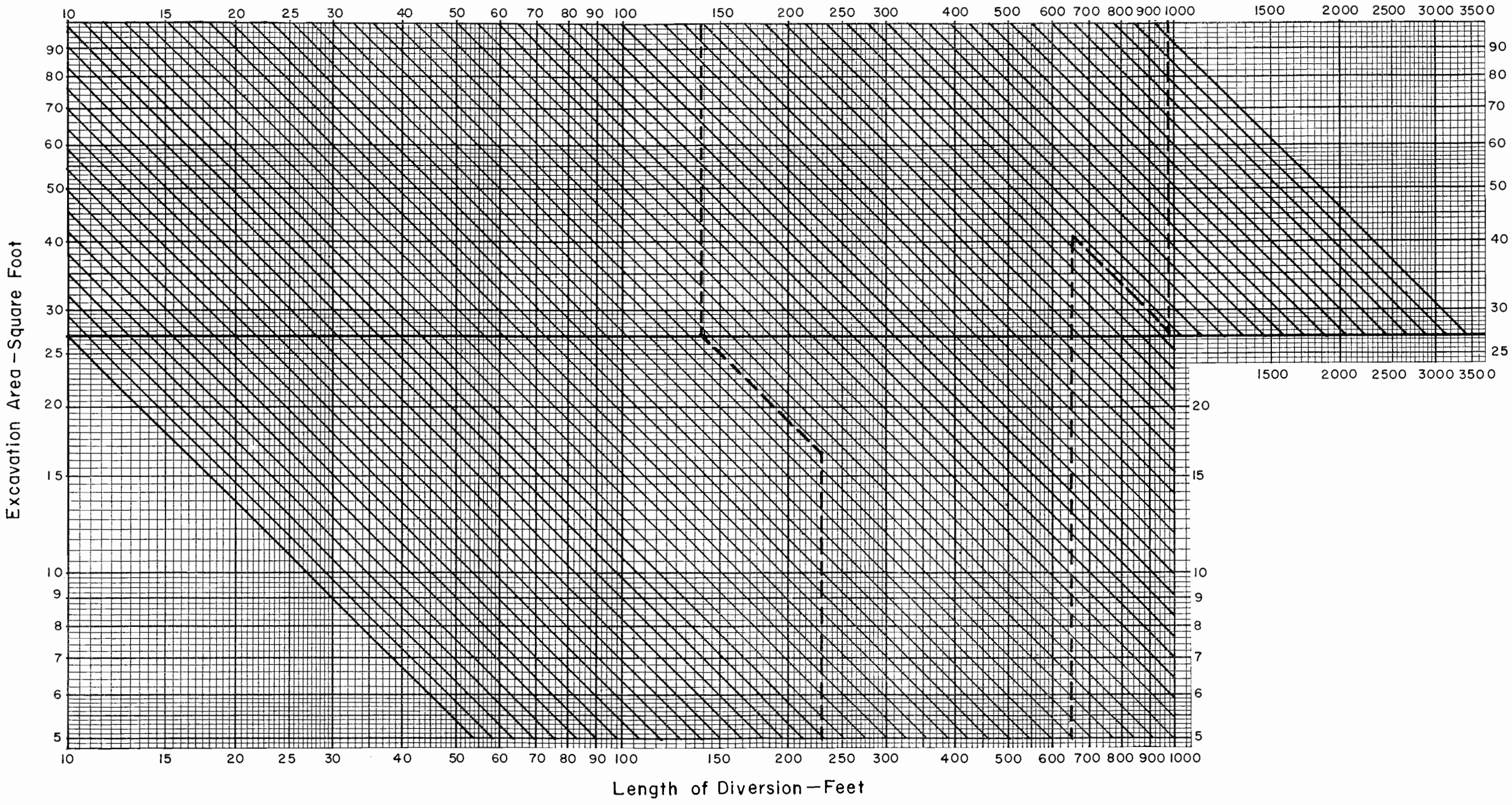
CHANNEL CENTER LINE DEPTH OF CUT 1/ AND AREA OF EXCAVATION 2/
FOR
DIVERSIONS WITH CUT-FILL RATIO 1.25:1.00
6:1 Channel and Ridge Slopes 4 Ft. Ridge Top Width

5% Land Slope

Total Height of Diversion Above Channel	Channel Bottom Width - Feet													
	4'		6'		8'		10'		12'		14'		16'	
	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area	Cut	Area
1.6	1.2	15.3	1.2	17.3	1.2	19.3	1.1	21.3	1.1	23.2	1.1	25.2	1.1	27.1
1.8	1.4	18.2	1.3	20.5	1.3	22.7	1.3	24.9	1.2	27.0	1.2	29.2	1.2	31.3
2.0	1.5	21.4	1.5	23.9	1.4	26.4	1.4	28.8	1.4	31.1	1.3	33.5	1.3	35.8
2.2	1.6	24.9	1.6	27.6	1.6	30.3	1.5	32.9	1.5	35.5	1.5	38.1	1.4	40.6
2.4	1.8	28.7	1.7	31.6	1.7	34.5	1.7	37.3	1.6	40.2	1.6	43.0	1.6	45.7
2.6	1.9	32.8	1.9	35.9	1.8	39.0	1.8	42.1	1.8	45.1	1.7	48.1	1.7	51.0
2.8	2.1	37.2	2.0	40.5	2.0	43.8	1.9	47.0	1.9	50.2	1.9	53.4	1.9	56.5
3.0	2.2	41.8	2.2	45.3	2.1	48.7	2.1	52.1	2.0	55.5	2.0	58.9	2.0	62.2
3.2	2.3	46.6	2.3	50.3	2.3	53.9	2.2	57.5	2.2	61.0	2.1	64.5	2.1	68.0
3.4	2.5	51.6	2.4	55.4	2.4	59.2	2.4	62.9	2.3	66.6	2.3	70.3	2.3	73.9
3.6	2.6	56.7	2.6	60.7	2.5	64.6	2.5	68.5	2.5	72.3	2.4	76.1	2.4	79.9
3.8	2.8	61.9	2.7	66.0	2.7	70.1	2.6	74.1	2.6	78.1	2.5	82.1	2.5	86.0
4.0	2.9	67.2	2.9	71.5	2.8	75.7	2.8	79.9	2.7	84.0	2.7	88.1	2.7	92.2

1/ - In Feet 2/ - In Square Feet Per Foot

Yardage Conversion Chart for Diversions



To convert a given cross-sectional area of excavation for a diversion of specified length to total excavation in cubic years.

PROCEDURE: Locate point opposite square feet of excavation area and directly above diversion length. Follow angle lines to dark horizontal line, then vertically to top of chart and read cubic yards of excavation for the diversion. (If diversion exceeds 1000 ft. in length, compute yardage for length segments and add together.)

EXAMPLES:

1. Cross-section area = 16.4 sq.ft. (excavation)
   Length = 230 ft.
   Total excavation = 138 cu. yds.

2. Cross-section area = 40.8 sq.ft. (excavation)
   Length = 650 ft.
   Total excavation = 980 cu. yds.

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5,N-20,295

CONTENTS

PART 7

DRAINAGE

Subject	Page
1. General	7-1
Definition	7-1
Adaptability, Benefits and Limitations	7-1
Relationship to Other Practices	7-2
Areas Requiring Drainage	7-2
Surface Drainage	7-2
Subsurface Drainage	7-4
Types of Drainage Systems	7-5
Surface	7-5
Subsurface	7-8
Preliminary Examination of Drainage Enterprises	7-9
2. Design	7-16
Surface Drainage	7-16
Surveys	7-16
Design of Surface Drains	7-18
Drainage Coefficients	7-18
Subsurface Drainage	7-35
Surveys	7-35
Design of Subsurface Drainage	7-50
Drainage Coefficients	7-54
Depth and Spacing of Subsurface Drains	7-57
3. Layout	7-57
Staking	7-57
Large Drains	7-57
Small Farm Drains	7-58
Subsurface Drains	7-58
Closed Subsurface Drains	7-58
4. Construction	7-58
Subsurface or Open Drains	7-58
Subsurface or Covered Drains	7-60
5. Maintenance	7-60
Open Drains	7-60
Covered Drains	7-61

LIST OF FIGURES

PART 7

DRAINAGE

Figure Number	Title	Page
7.1	Surface Drains- - - - - - - - - - - - - - - - - - - -	7-6
7.2	Numbering of Drains - - - - - - - - - - - - - - - - -	7-7
7.3	Relief Drains - Open and Closed Types - - - - - - - -	7-10
7.4	Interception Drains - Open and Closed Types - - - -	7-11
7.5	Relief Drains in Series - - - - - - - - - - - - - - -	7-12
7.6	Delineation of Drainage Areas - - - - - - - - - - -	7-19
7.7	A, B, C, D Curves - - - - - - - - - - - - - - - - - -	7-20
7.7-1	A, B, C, D Curves - - - - - - - - - - - - - - - - - -	7-21
7.8	M and S Curves- - - - - - - - - - - - - - - - - - - -	7-22
7.9	Permissible Canal Velocities- - - - - - - - - - - - -	7-27
7.10	Ditch Design (Example)- - - - - - - - - - - - - - - -	7-30
7.11	Capacity of Corrugated Metal Pipe - - - - - - - - -	7-33
7.12	Corrugated Pipe Culverts - Free Outlet- - - - - - -	7-34
7.13	Topographic Map of Irrigated Farm with High Water Table Condition - - - - - - - - -	7-41
7.14	Observation Well Data - - - - - - - - - - - - - - - -	7-43
7.15	Interception Drain at Base of Hill or Terrace - - -	7-45
7.16	Interception Drain Above Underground Barrier- - - -	7-47
7.17	Interception Drain at Base of Permeable Aquifer - -	7-48
7.18	Interception Drain with Relief Wells- - - - - - - -	7-49
7.19	Closed Interception Drain Located Above Constricted Aquifer - - - - - - - - - - - - - - -	7-51
7.20	Relief Drain in Low Area- - - - - - - - - - - - - - -	7-52
7.21	Relief Type Drains- - - - - - - - - - - - - - - - - -	7-53

PART 7

DRAINAGE

1. GENERAL

Definition

Drainage is defined as the removal and disposal of excess water from agricultural lands by artificial methods. The excess water may be water which accumulates on the land surface, or it may be excess ground water causing a high water table condition in or near the root zone.

Surface drainage is defined as the removal and disposal of excess surface water, from any source, which is present above the ground surface.

Subsurface drainage is defined as the removal and disposal of excess ground water which is causing a high water table condition to exist. Ground water is defined as any free or gravitational water present below the surface of the ground.

Adaptability, Benefits and Limitations

Agricultural drainage is adaptable to most areas where excess surface water or ground water is a problem. Open ditches are usually employed for surface drainage and either open ditches or covered drains are used for subsurface drains. The type of drainage system to be installed must be adapted to topographic, climatic, soil, subsoil, and ground water conditions present. Each drainage problem requires individual consideration of existing conditions and the system planned must be tailored to fit local conditions. In areas of extremely heavy soil, with very slow permeability, it may not be possible to effect good drainage. This condition must be recognized and made known to the landowner. In some areas adverse topographic conditions may virtually prohibit establishing agricultural drainage. This is true of some closed-basin or pothole areas where the cost of establishing an outlet may be excessive. There are also areas of alkaline soil, which in addition to needing drainage, may require costly treatment with chemical amendments. Where these conditions are present, the cost of reclamation through drainage may be prohibitive.

Agricultural drainage is beneficial in many ways. It makes possible timely farming operations without delay because of wetness. Soil bacterial action is improved by removing water from the pore spaces in the soil. The roots of plants and the soil bacteria must have access to oxygen from the air. Soils that are properly drained will "warm up" more quickly than super-saturated soils, and this permits earlier planting and better germination. In cases where the water table is lowered through drainage, the active root zone depth is increased allowing plants to develop their natural root patterns. Where excessive soluble salts are present in the soil profile, good subsurface drainage will establish downward percolation

1. GENERAL (CONT'D)

Adaptability, Benefits and Limitations (cont'd)

of water in the soil profile, and will permit leaching of the soluble salts. These are but a few of the many benefits to be realized through good drainage.

The limitations on agricultural drainage are few, but important, and should be stressed. Land use capability should be determined in advance of drainage planning to insure that the lands drained will be improved sufficiently to warrant the expense of drainage. There are limitations on drainage in areas of "droughty soils", subject to a high water table and where the crops are subirrigated. In all cases the cost of drainage must be determined and weighed against the anticipated benefits.

When designing or installing drainage systems, compliance with state laws on the diversion or drainage of water must be adhered to.

Relationship to Other Practices

Agricultural drainage is one of many conservation practices applied to the land. It should be conceived and planned as a part of the overall farm or ranch plan and should be integrated with other land treatment practices.

In irrigated areas the function of drainage is to remove excess irrigation waste water, runoff from precipitation, and to lower water table levels. It is essential that every irrigation system be provided with a surface drainage system to dispose of runoff and waste water. In developing plans for a new or prospective irrigation system, surface drains should be planned as an integral part of that system. The need for subsurface drainage may or may not be evident at the time of planning the irrigation system; however, provision should be made for a main outlet system for subsurface drainage in the event that it is needed.

Wherever fields are considered for land leveling, smoothing or grading operations, surface drainage should be planned as a part of that operation. The plan for leveling or grading should consider the conveyance of all excess surface water to a planned drainage system.

Areas Requiring Drainage

Surface Drainage. Surface drainage is necessary on all lands where flooding and inundation cause frequent damage to crops. Surface drains are seldom designed to remove the peak flood flow from any given drainage area. Usually the drains are designed to remove only a part or portion of the peak flow as most crops can tolerate some degree of flooding without damage. Drains are designed to remove a certain quantity of water based on the removal of a certain depth of water from the land surface in a period of 24 hours. These rates of removal vary for different areas, but are in the general range of 3/8-inch to one inch removal in 24 hours. This rate of removal is often given in terms of "cubic feet per second per unit area" rather than in inches removal in 24 hours.

1. GENERAL (CONT'D)

Areas Requiring Drainage (cont'd)

Surface Drainage (cont'd)

In extremely flat areas where there is no appreciable slope to the land surface and where there are minor undulations, surface drainage is usually a major problem. In areas such as this, land smoothing or grading to fill in the low areas is an accepted practice and will reduce damage or crop loss considerably. This is a practice that can be employed regardless of the other drainage facilities installed. The practice of bedding has been used with some success on extremely flat lands. Bedding involves dividing a field into narrow lands 30 to 100-feet in width similar to the strips laid out for strip cropping practices. Each bed or land is plowed as a separate field with the back furrow in the center of the bed and dead furrows on both edges. Plowing in this manner over a period of years tends to form a crown in the center of each bed or land and provides a slight slope or gradient to the dead furrows. These dead furrows serve as shallow field drains - each drains an area equal to the area of the bed. An outlet ditch must be provided to serve as a main outlet for these field drains made by the dead furrows.

Flat lands with inadequate natural surface drainage are the most common problem encountered in surface drainage work. It includes a large group of problem areas where there is some degree ofnatural surface drainage but not enough to prevent frequent damage from flooding. The existing natural drainage pattern must be supplemented by surface drains designed to remove the quantity of excess water as computed by applying the proper drainage coefficients to the area drained. There is no standard or set pattern for surface drainage systems of this kind. The location and spacing of drains is usually dictated by topographic conditions, soil conditions and by cultural features.

Closed basin or pothole areas are common in many regions. Providing surface drainage for these areas involves a careful consideration of topographic conditions as well as the features of the outlet. Economic and land capability considerations are very important. The potential value of the reclaimed area should be carefully weighed against the cost of drainage construction. The present land use should also be carefully considered in light of the potential land use. Small pothole areas located in large field hinder and slow up farming operations and are considered "nuisance areas".

Land subject to periodic flooding from rivers and streams includes the floodplain areas adjacent to rivers or streams. The problem in these areas is to provide surface drainage of the depressions and low areas present in the floodplain area subsequent to the return of the stream to its normal channel. Open-type gravity drains are generally used to correct this situation, however, there is an element of danger involved in using open-type drains where channel-changes may take place. This is a point that should be given careful study and consideration. Where there is a possibility of channel-changes taking place, open drains may be diked on

1. GENERAL (CONT'D)

Areas Requiring Drainage (cont'd)

Surface Drainage (cont'd)

their stream side and restricted culvert-type surface water outlets provided to the open drain. Another method is to install tile drains with restricted surface water inlets. Either of these methods will reduce the possibility of channel-changes taking place.

Levee lands constitute a special problem in areas adjacent to major streams and rivers where levees or dikes have been installed. The problem in these areas is to provide an outlet for drainage systems during the period when the stream or river is in flood stage. During periods of low stage, gravity outlets will provide drainage through gates in the levee. During high stages drainage can be provided by automatic pumping stations at strategic low points along the levee. As this is a rather specialized problem in drainage, it will not be covered in this handbook. Reference is made to U.S.D.A. Technical Bulletin No. 1008 entitled "Drainage and Operation of Drainage Pumping Plants".

Subsurface Drainage. In non-irrigated areas high water table conditions are caused by a combination of adverse soil and climatic conditions. Usually this occurs in areas of high rainfall and with soils that have rather slow internal drainage. As a result of this set of conditions, the water table will rise causing damage to crops. The solution to this problem lies in providing either open or closed-type subsurface drains at a depth and with a spacing sufficient to lower high water table levels. The most common practice used is to install tile drains on some uniform pattern such that the highest elevation of the new water table surface established will be low enough to permit proper plant growth.

There are also some high water table areas that are topographically low in relation to the surrounding general area. Because of their low position, the water table is too close to the land surface for good crop production. Examples of these would be "slope-break" areas along major valleys and isolated depression areas caused by glacial action. The treatment of these areas is the same as for other high water table areas. The problem is often difficult to visualize and to recognize in the field.

Geologic conditions are sometimes responsible for isolated wet areas. Subsurface explorations generally reveal that these geologic formations are retarding or preventing ground water flow, thereby causing a localized high water table condition. Situations of this kind require extensive boring to locate underground barriers and to determine their extent and effect on ground water levels. It is usually advisable to enlist the services of a geologist to interpret these conditions.

High water table conditions requiring subsurface drainage are common in irrigated areas. The chief reasons for these conditions are poor irrigation methods, careless irrigation operations and lack of adequate waste water disposal systems. Improved irrigation methods and practices can

1. GENERAL (CONT'D)

Areas Requiring Drainage (cont'd)

Subsurface Drainage (cont'd)

materially reduce subsurface drainage problems, however, even with the highest irrigation efficiency obtainable, there may be extensive areas that will require subsurface drainage. Under most systems of irrigation there is some loss of water through deep percolation. The water lost through percolation increases the amount of ground water present in the soil and subsoil and this may be sufficient to raise water table levels. The solution to the problem lies, first, in increasing irrigation efficiencies to their maximum and secondly, in providing subsurface drainage for those areas remaining wet. Drainage systems may be constructed with either open-type or covered-type drains.

Types of Drainage Systems

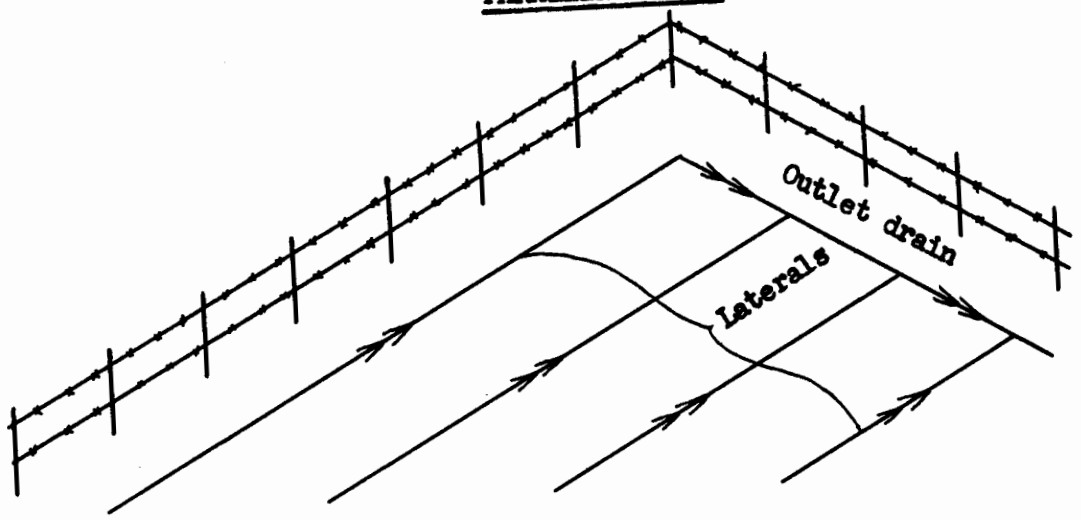
Drainage systems are classified as surface drainage systems or subsurface drainage systems in accordance with the function they serve and the definitions as given on Page 7-1.

Surface. Surface drainage systems are planned and designed to remove excess surface water and to reduce flooding and inundation. There is no standard or set pattern for the location of surface drains. They may be random systems, herringbone systems, parallel systems, or any one of several patterns that will fit topographic conditions. (See Figure 7.1). In hilly or rolling areas with considerable relief, random-type drains are usually employed. Drains are located so that they will reach all the low or depressed areas and remove excess surface water. In flat areas with little or no relief, regular patterns of surface drains such as the parallel or herringbone system will usually be employed.

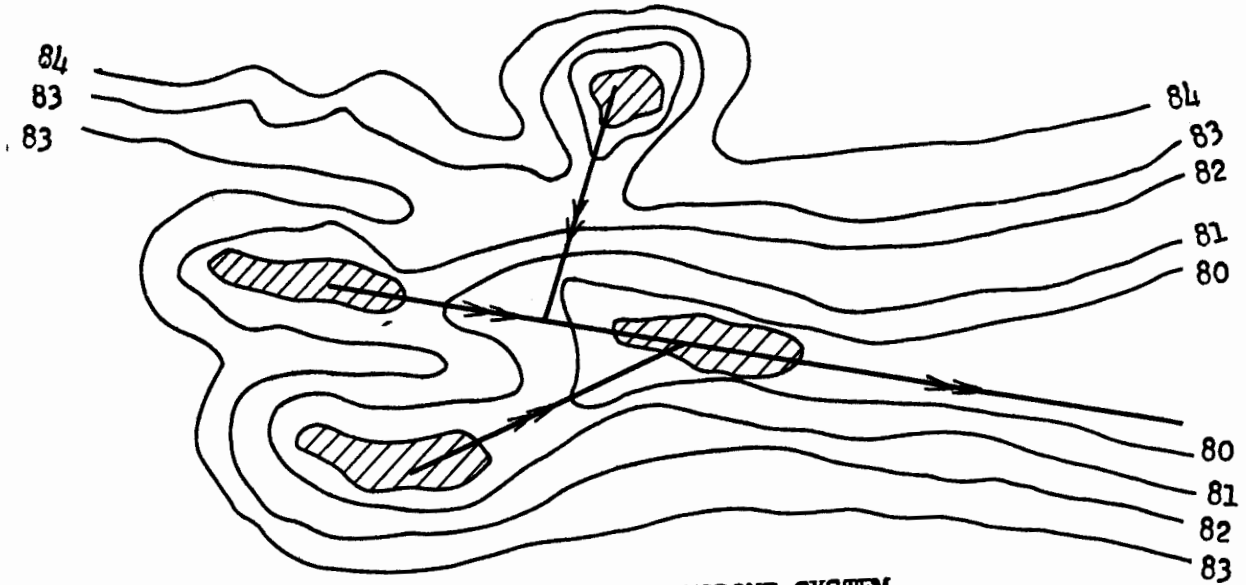
Surface drains are usually open ditches, however, in some few special cases, closed drains with surface water inlets may be used. These closed drains may be similar in design to city storm-sewer systems. Open ditches employed as surface drains may have any one of several cross sections varying from V type to U type or trapezoidal cross section. The cross section chosen is dependent upon farming operations, ditch capacity, permissible ditch velocities, and the relative cost of construction. Trapezoidal ditches with side slopes varying in the range of 1:1 to 10:1 are most commonly used. V-shaped ditches with side slopes of about 4:1 or flatter are sometimes used as field drains.

In systems having one or several lateral drains, the outlet drain is often referred to as the main, and tributaries are referred to as laterals, sublaterals or field drains. To avoid confusion in terminology, each drain in a system of drains should be numbered to identify it within the system. The decimal system as illustrated by the drawing in Figure 7.2 is suggested as it is in common use in irrigation practice and is equally adaptable to drainage practice.

PARALLEL SYSTEM



RANDOM SYSTEM



HERRINGBONE SYSTEM

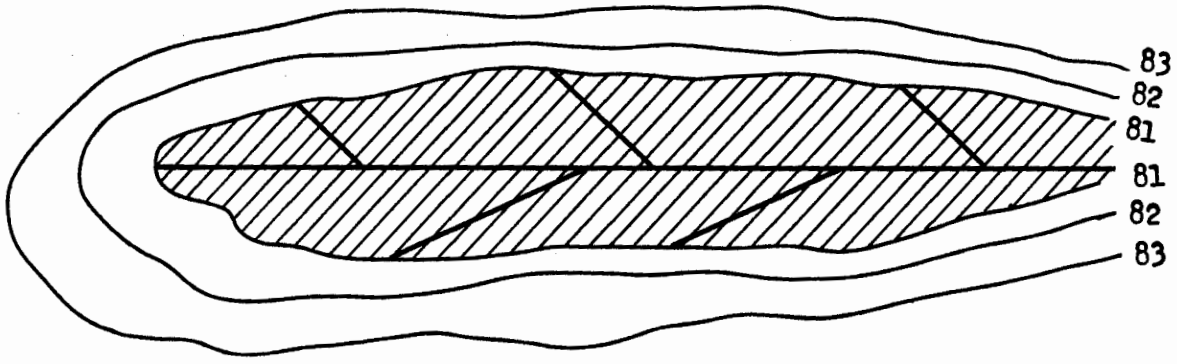
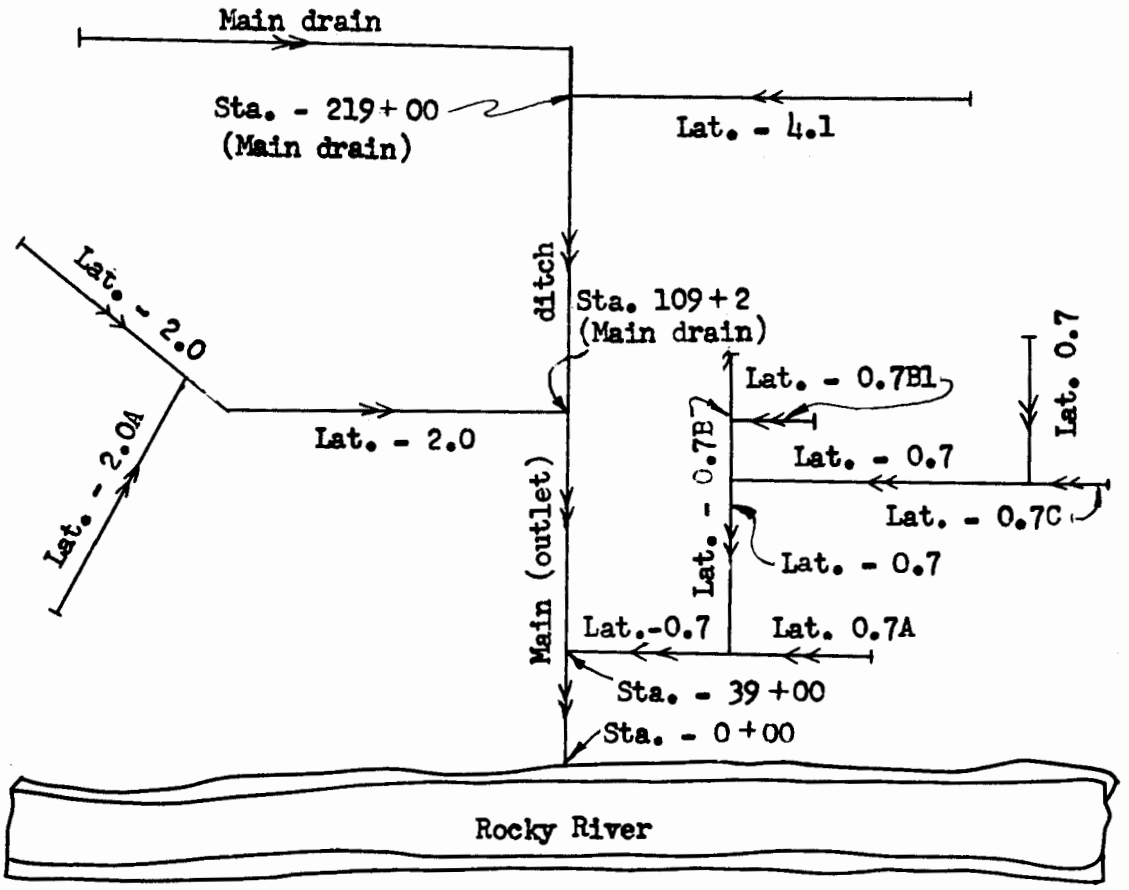


Figure 7.1



Introduction to the Numbering of Drains.

(1) Main or outlet ditch is labeled "Main Ditch" or "Outlet Ditch".

(2) Each lateral outletting directly into main ditch is labeled with a number indicating the main drain stationing to the nearest tenth mile.

(3) Each sub-lateral is labeled the same as the lateral to which it outlets, and a letter is added starting with letters A for the first sublateral, B for the second sub-lateral, etc.

(4) If additional laterals are outletted to sub-laterals, they may be identified by adding a number series such as Lat-0.7B1, etc.

Figure 7.2

1. GENERAL (CONT'D)

Types of Drainage Systems (cont'd)

Subsurface. Subsurface drainage systems are planned and designed to lower existing high water table levels by removing excess ground water. Subsurface drainage systems like surface drainage systems may, or may not, be laid out on a standard or fixed pattern. This is dependent upon local situations and must be determined on the basis of conditions at each site. In interception type systems, drains are usually random drains and the location of individual drains is fixed by the direction of ground water flow and the permeability of soil and subsoil materials. In relief type systems, drains are usually laid out on a parallel or herringbone pattern, but may be planned as random drains where the problem areas are isolated tracts.

Subsurface drains may be either open-type or covered-type drains. Both serve essentially the same purpose of lowering high water table levels and each have advantages and disadvantages.

Advantages of open subsurface drains are:

(1) They are usually accessible for maintenance and can be designed on very flat grades (below silting velocities) and maintained regularly.
(2) They are usually deep drains and have a capacity considerably in excess of that required for ground water removal, consequently they usually have ample capacity for the removal of both surface water and ground water.

Disadvantages of open subsurface drains are:

(1) They are usually wide because of the required depth and require a right-of-way varying from 50 to 100-feet.
(2) The exposed ditch area requires constant maintenance to combat weed and brush growth.
(3) Sediment accumulation is rapid and rehabilitation is usually necessary in 10 to 15 years.

Advantages of covered subsurface drains are:

(1) The area where the drains are located can be leveled and farmed with no loss of land.
(2) If properly designed and constructed, maintenance will be at a minimum.

Disadvantages of covered subsurface drains are:

(1) If drains become clogged or stopped, repairs and maintenance may be very difficult and expensive.
(2) Closed drains are limited to conditions where grades will give scouring velocities for fine sediments. This may prohibit their use in extremely flat areas.
(3) They can seldom be used as dual purpose drains for removal of both surface and subsurface water due to the excessive cost of providing additional capacity for surface runoff.

1. GENERAL (CONT'D)

Types of Drainage Systems (cont'd)

Subsurface (cont'd)

Subsurface drains, either open or covered-type, are classified as relief or interception drains depending on how they are oriented with respect to ground water flow. Relief drains are oriented parallel to the direction of ground water flow and interception drains perpendicular to the direction of ground water flow. This is illustrated in Figures 7.3 and 7.4.

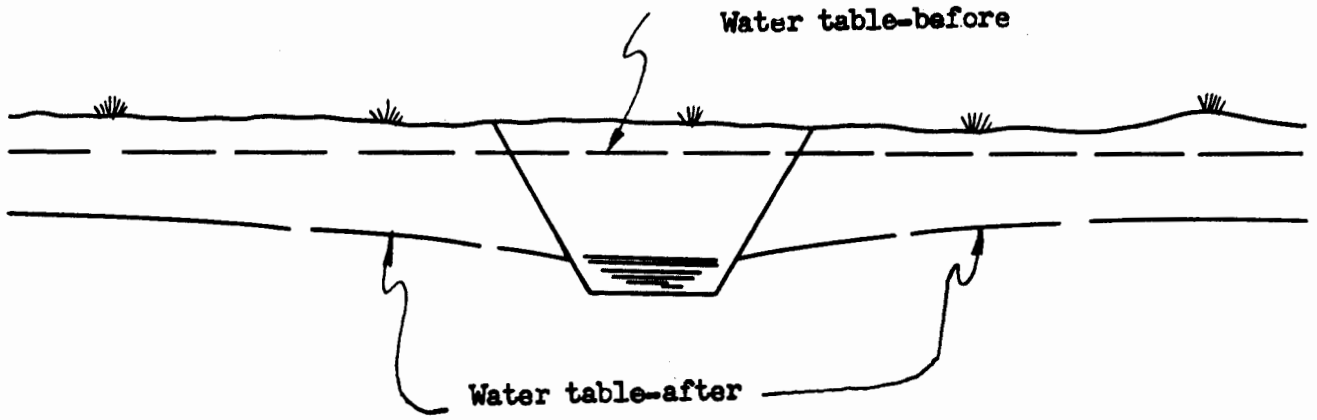
Interception drains are used where there is appreciable slope to the water table and where it is possible to construct a deep drain above the affected area to cut off ground water flow. Relief drains are used where the water table is very flat and where there is no appreciable ground water flow or movement. Relief drains are often planned in a series of parallel systems where the function of each drain is to lower the water table to a point midway between it and the adjacent drains. This is illustrated by Figure 7.5.

Preliminary Examination of Drainage Enterprises

When an application for technical assistance in drainage is received, the first step is to make a preliminary examination of the job or project. This preliminary examination should include a field inspection to determine the location and extent of the problem area, the number of ownerships involved, whether the problem is surface or subsurface drainage, and the desires and intentions of the landowners in regard to drainage. From this general information it can be established that the project will be either a group enterprise or an individual job. The magnitude of the work can be estimated and a general plan of the type of drainage works required can be formulated. Knowing the desires of the landowners, the general feasibility of proceeding further with drainage surveys, studies and investigations can be determined. If, on the basis of these conditions, the project appears feasible, a more detailed preliminary examination of topographic, soil, subsoil, outlet and ground water condition must be made. The situation as to easements and rights-of-way must be investigated. Maps or documents containing information on engineering problems in the particular area should be consulted. Aerial photography coverage is usually available. One set of four or eight-inch aerial maps should be obtained for planning purposes. A search should be made to determine if useful maps or plans are available from the U. S. Geological Survey, Corps of Engineers, Bureau of Reclamation, or other state, county, or private agencies. Appropriate federal, state, county, and private agencies should be contacted to determine if previous drainage studies have been conducted in the area, and if so, copies should be obtained and studied.

In new work areas, the status of existing improvement districts or drainage organizations or districts, if any, should be determined. If the tract under consideration is within such an organized area, the proposed

RELIEF DRAINS - OPEN TYPE



RELIEF DRAINS - CLOSED TYPE

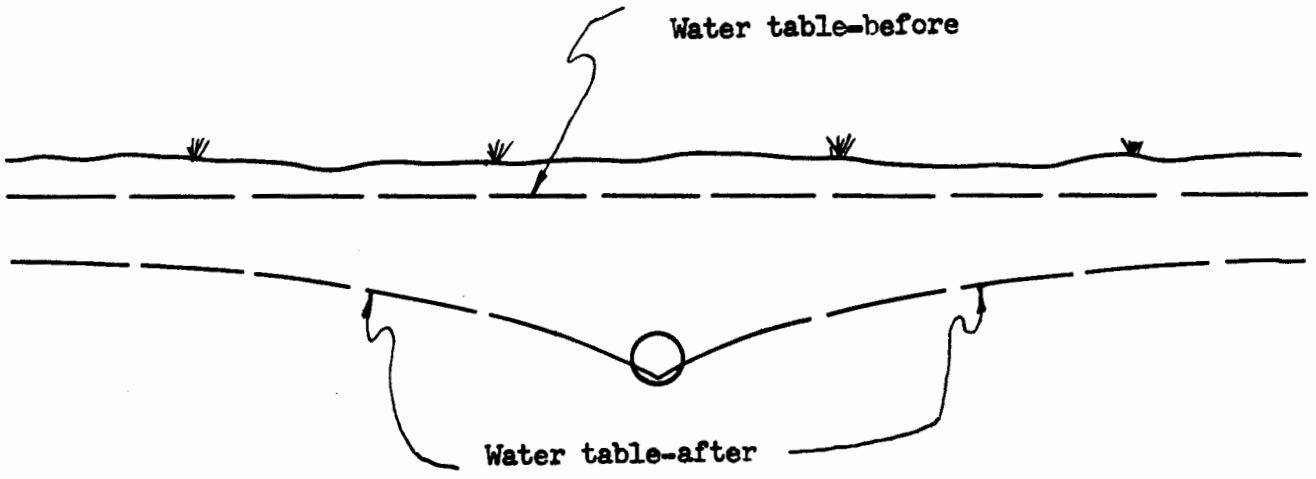
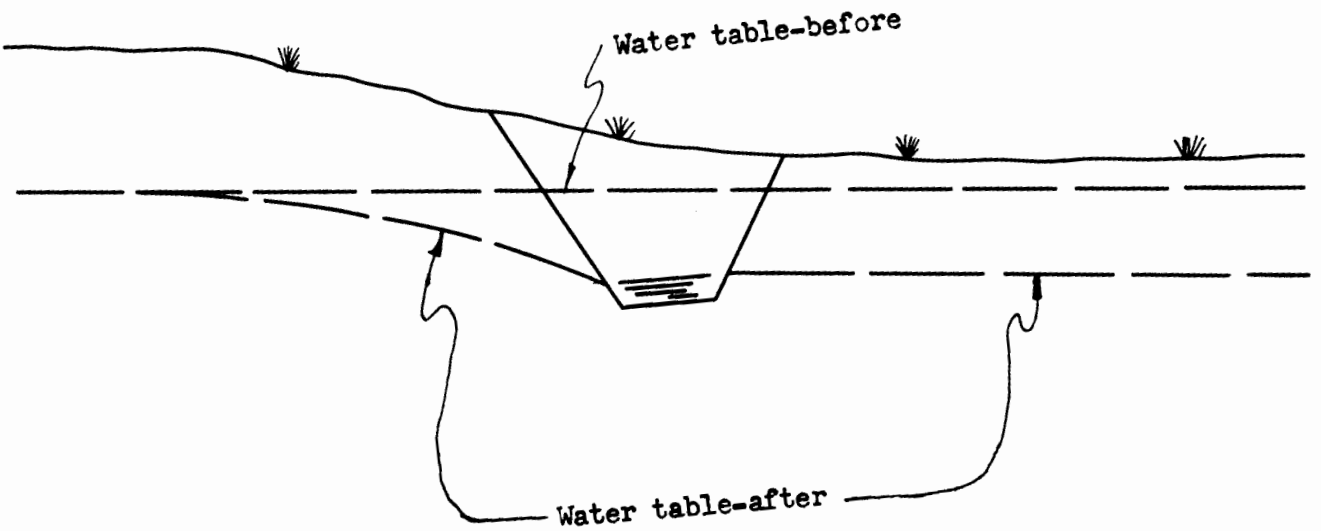


Figure 7.3

INTERCEPTION DRAINS - OPEN TYPE



INTERCEPTION DRAINS - CLOSED TYPE

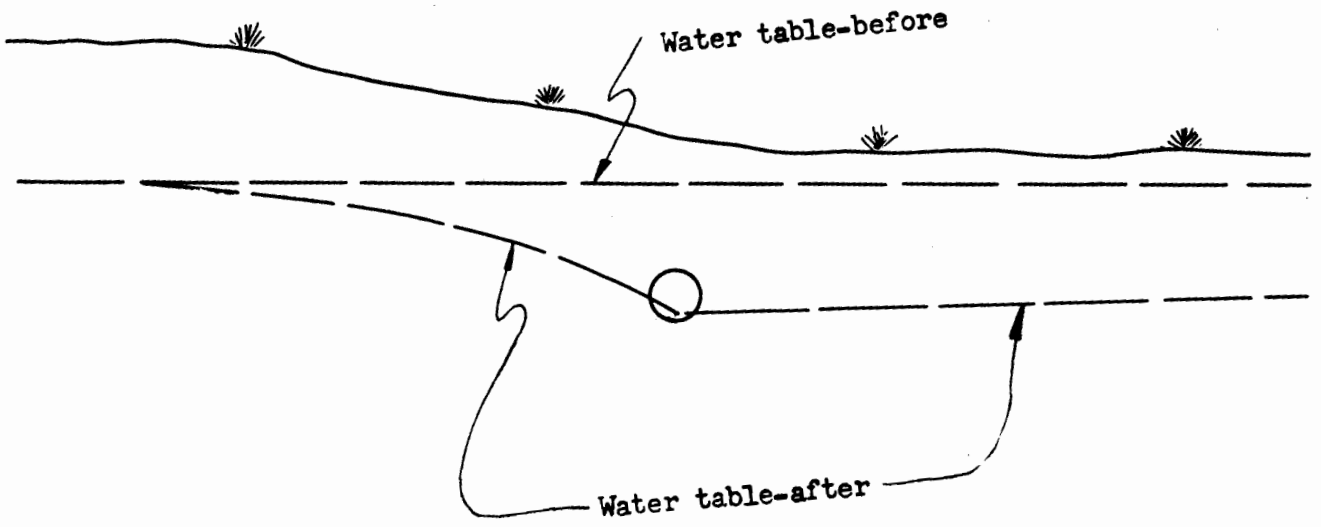
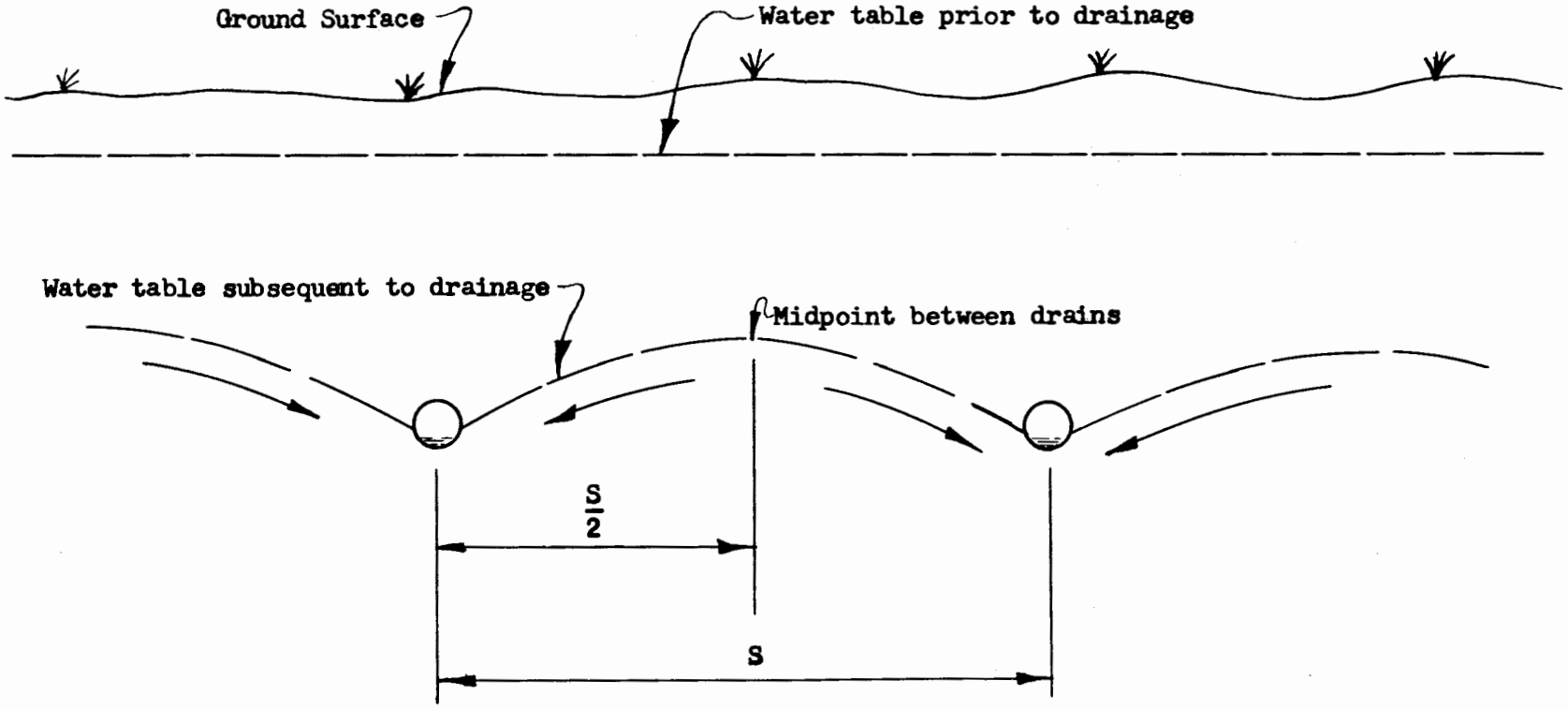


Figure 7.4



S = spacing between drains

RELIEF DRAINS IN SERIES

FIGURE 7.5

1. GENERAL (CONT'D)

Preliminary Examination of Drainage Enterprises (cont'd)

work should be reviewed to determine how it fits in with the organizational plan. Quite often rules, regulations or laws may require certain concurrence or approval of proposed works planned to supplement or replace existing works.

If the area is not in a drainage district or other comparable organization, consideration should be given to the necessity of such an organization. Small projects involving one or two landowners can usually be handled through mutual agreements as between landowners. This may not be true, however, where it is necessary to force or condemn rights-of-way for proposed drainage works. In large projects involving many landowners, it is usually necessary for the landowners to form some type of organization either mutual or corporate to expedite the legal and financial arrangements.

A general reconnaissance of the area should be made to view general topographic conditions. The location and size of natural waterways should be noted. Average land slopes should be determined. The condition of natural or existing artificial drains should be observed and noted. The position of the area to be drained with respect to the watershed area should be determined. Usually most of the above information can be obtained without making instrumental surveys. It may be helpful at times to make a few instrument observations to determine slopes, depths and cross sectional areas of important waterways or existing drains. It may also be advantageous to use an instrument to determine the boundaries of the drainage area.

Soil surveys are available or can be secured for most areas planned for drainage. Information given by these surveys includes structure, texture, permeability, slope and other soil conditions pertinent to drainage. Investigations to determine the degree of salinity and alkalinity are not normally a part of regular soil surveys, but can be obtained on special request where necessary. Facilities for laboratory analysis are available at existing soil conservation facilities. Quite often it is possible to make arrangements with agricultural colleges for laboratory analysis work.

The treatment of saline, saline-alkali and alkali soils where they are present in wet areas is most important. Reference is made to Agricultural Handbook No. 60, entitled "Diagnosis and Improvement of Saline and Alkali Soils" which is an excellent treatise of the subject. Saline soils (soils with a high percent of soluble salt) can usually be reclaimed through drainage and leaching. Alkali soils (soils with a high percentage of insoluble salts) usually require treatment with chemical amendments prior to drainage and leaching. Saline-alkali soils (soils with appreciable quantities of both soluble and insoluble salts) present a complex situation which is not simple. When these soils are encountered in drainage practice, the technician should consult with a competent soil scientist prior to planning drainage works.

1. GENERAL (CONT'D)

Preliminary Examination of Drainage Enterprises (cont'd)

Subsoil and substrata conditions are particularly important in subsurface drainage work where drains are excavated below the normal soil profile. In soil survey work, as carried out by the Service, subsurface explorations are made to a maximum depth of about five feet. Where drains are to be excavated below five feet, it is necessary to supplement soil survey information with deeper exploratory borings. The condition of sediment below the drain are important as they may exert a marked effect on ground water yield to the drain. It is usually advisable to determine texture, structure and the permeability of sediments to some depth below the proposed depth of the drain and can be done by some type of boring machine.

The investigation of outlet conditions is important and should have a high priority in preliminary investigations. The adequacy of the outlet or outlets should be judged on the current and proposed land use. As the land use in a drainage area is intensified and additional drainage works installed, an increasingly larger outlet will be needed. If new drainage works are proposed at the outlet, the most intensive use expected of the entire drainage area must be considered in developing the outlet.

A study of the frequency of high water stages in the streams, rivers or lakes serving as outlets is needed. The average elevation during a 24-hour flood of five year frequency is a valuable guide in determining the flow line (hydraulic gradient) at the outlet. Available river or stream gauge records should be used in making these determinations. Where such records are not available, the best possible estimate should be made based on local observation of high water marks and through discussions with local people or by computing stage frequency relationships in accordance with the methods outlined in the Hydrology Handbook.

Where satisfactory gravity outlets do not exist, pumping should be considered before deciding that the project is impractical. A few conditions affecting the economic justification for pumping are listed below:

(1) Height of pumping lift in feet.
(2) Volume of water in acre feet per acre to be pumped annually.
(3) Value, if any, of the water when pumped.
(4) Estimated annual increase in net returns per acre following drainage.
(5) Percentage of the year the pump would have to operate.

Surface water as it pertains to drainage includes runoff from precipitation which may be ponded in low areas and waste water from irrigated areas. Surface water conditions must be investigated to determine frequency and time of flooding or inundation, depth and duration of flooding and the amount of siltation if any. The damage caused by flooding or inundation of agricultural areas depends upon the land use, crops grown, and the time and duration of flooding. It is impossible to generalize on damages unless these factors are known. The landowner or operator is usually very much aware of

1. GENERAL (CONT'D)

Preliminary Examination of Drainage Enterprises (cont'd)

damages and their frequency of occurrence and therefore, may be the best source of information. The useful life and amortization period of open drainage systems ordinarily will range from 5 to 30 years for large systems and from 5 to 15 years for small systems.

In irrigated areas waste water disposal must be provided for, in addition to the disposal of surface runoff from precipitation. All irrigated lands must be provided with drains for waste water disposal. The capacity of drains for waste water should be equal to 15 percent of the required irrigation stream capacity to serve the turnouts for the area involved on light soils, and 30 percent on heavy soil. The drains shall have a minimum capacity sufficient to carry the rated flow of any single turnout serving the area. The runoff from precipitation should be computed for the field and the drainage coefficient used that applies to that area. This amount is usually small and may not materially influence the design capacity because of the small size of fields in irrigated areas.

Ground water investigations are normally too involved to be undertaken as a part of preliminary investigations, however, it is often possible to make some estimate of ground water conditions present from or through consultation with local people. Existing shallow farm or ranch wells can be checked for water table level. Consulting with personnel associated with telephone, power line, gas line, or oil line companies is often a good source of information. Usually the local people in the area have some knowledge of ground water levels at least on their particular ownership. If these sources fail, it may be necessary to bore holes with a hand auger at strategic points and to actually measure the depth of the water table.

Vegetative cover is usually a good clue to water table conditions. Tules, cattails, rushes and sedges are water-loving plants and are quite often present in high water table areas. Certain types of brush and trees such as willows, poplar and cottonwood thrive in high water table areas. It is important that high water table areas be identified early during the preliminary examination as the type of system to be planned and the cost of construction may be altered considerably if there are extensive areas that require deep subsurface drains.

The installation of drainage systems quite often affects changes in land use. The present land use should be noted and considered in light of future or potential land use after reclamation through drainage. Generally the best agricultural lands, which are the flat bottom lands and low lands, are most severely affected by lack of surface drainage and high water table conditions. For this reason much of the land reclaimed through drainage develops into choice farm land.

Special emphasis should be placed on land use considerations where land not currently in agricultural use will be returned to such use. This is also true of land currently in use as wild life habitat which will be

1. GENERAL (CONT'D)

Preliminary Examination of Drainage Enterprises (cont'd)

converted to crop land. Where these situations arise and where they appear controversial, they should be referred to the district supervisors of the local soil conservation district involved and to higher administrative authority within the Service.

Securing easements and rights-of-way where necessary is a function of the landowners, drainage organization or sponsoring agency concerned. It is not a function of the Service. Where it is obvious on initial investigation that easements and rights-of-way must be secured in order to install appropriate drainage works, it may be advisable to request landowners to ascertain these possibilities in advance of detailed planning. Such precautionary measures may result in substantial savings of Service time on work that cannot materialize because of legal or financial entanglements.

Reports of preliminary examination should be prepared in all cases. If the preliminary examination covers work on only one or two farms and the project has no special complications, the report may be no more than a few pertinent comments and remarks attached to and filed with the conservation plan. If the project is a large project involving several landowners and with the complicating factors, a more formalized preliminary examination and report should be prepared. This report should contain the applicable items as previously listed. For more detailed information on the preparation of preliminary examination reports, refer to Section 16, National Engineering Handbook or memorandum of state policy. The services of area and/or state specialists will usually be available on larger group enterprises.

2. DESIGN

The following information deals specifically with surveys and investigations preparatory to the actual design of small drainage systems that may be planned and designed without the assistance of the engineering specialists. A more comprehensive treatment of this subject prepared for engineers engaged in drainage work is given in Section 16, National Engineering Handbook. Related subjects; namely, hydrology, hydraulics and structural design are covered under Section 4, 5, and 6 of the National Engineering Handbook.

Surface Drainage

Surveys. Upon completion of the preliminary examination, if the project appears feasible, it is necessary to conduct certain surveys and investigations to obtain detailed information for the design of surface drains.

A large scale topographic map is extremely useful in locating drains, determining drainage areas, existing grades and in selecting the type and pattern of system to be used. Experience indicates that maps on a scale of 200 to 500-feet per inch and with a vertical interval of 0.5-foot to

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Surveys (cont'd)

five feet are most applicable to drainage work. The complexity of the surface topography determines the degree of detail required. In extremely complex areas it may be necessary to make complete topographic maps of the area under consideration. In areas with less complicated topography a satisfactory map may be compiled by mapping only a portion of the area (strip-topography or spot-topography). In areas with rather obvious relief and where the topography is easily visualized, the location for drains may be established by inspection. Where this can be done a center line profile and cross section survey is adequate. Refer to Part 1 for additional details and examples of survey work. Aerial photos are often used as base maps for topographic work. Spot elevations can be plotted on aerial photos and from this information drain locations can be made.

The completed map, however prepared, should show the landowners' name, locations of proposed ditches, bridges, culverts, farm boundaries, watershed boundaries, section lines, roads, railroads, pipe lines, utility lines and any other pertinent cultural features.

Soil characteristics and properties have a very important bearing on the design of drains. In addition to the information on soils which may be obtained from a soils map, borings should be made at intervals dependent on soil changes along the proposed ditch location. For uniform soils borings at 2,000-foot intervals may be adequate. For alluvial soils borings may be required at intervals of 100-feet or even less. It is impossible to generalize upon the exact spacing as it is dependent upon the soil and subsoil formations at each particular site.

The initial depth and spacing of borings should be specified in the survey outline. The spacing and depth may need to be altered as the survey progresses to establish all changes in soil and substratum structure to a minimum depth of at least one foot below the anticipated depth of the ditch. Logs of all borings should be shown on the profile sheets.

Where drainage systems discharge into streams, natural draws, existing artificial ditches or lakes, the adequacy of the outlet must be checked. It is often obvious on inspection that outlets are more than adequate. For example, where small drains discharge into larger streams or rivers. In cases where it appears that the outlet capacity may be questionable, it is advisable to consult with the Area Engineer who has access to methods of computing outlet capacities. In some instances, the duration of flood stage in rivers may be the controlling or limiting factor rather than total capacity.

The present land use must be investigated to determine the acreage in crop land, pastures, hay land, brush and timber areas. These areas with different land use should be noted or plotted on a suitable map to be used when selecting drainage coefficients.

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Surveys (cont'd)

In planning drainage systems, especially small projects, special consideration should be given to the type of construction equipment that will be available. If the choice of equipment is known in advance, the designer can often vary his design to better accommodate that equipment. This is often the case where landowners have or own small ditchers, backhoes, farm tractors, bulldozers, etc. for use on their farms or ranches.

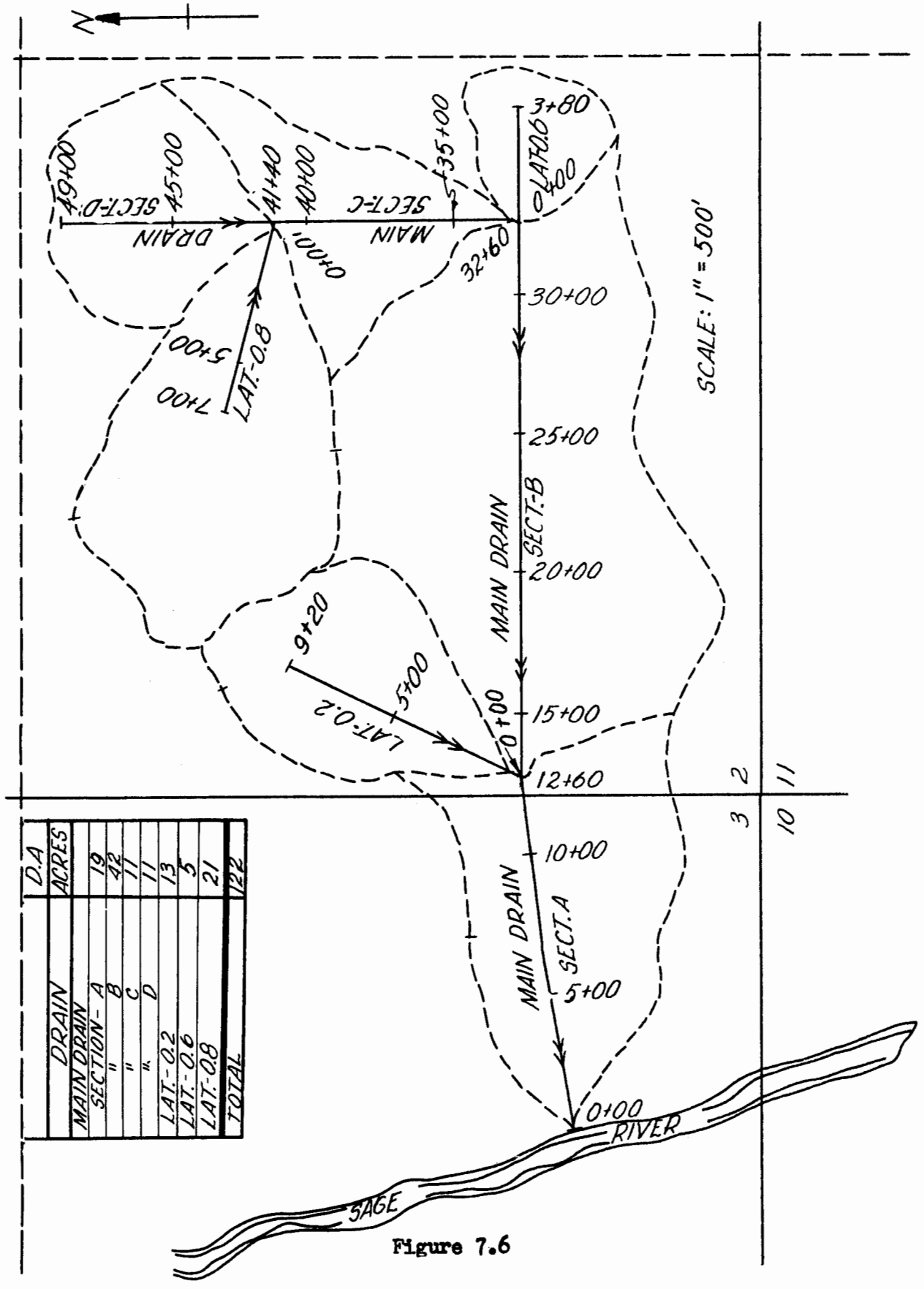
Design of Surface Drains. The first step in design after making tentative locations for drains is to plot these locations on a suitable base map. This map may be a topographic map, aerial photograph, or other suitable map, as the case may be. Each drain when located should be numbered as outlined in Figure 7.2, and the appropriate survey stationing shown. After the drains are located on the map, the drainage area served by each drain in the system should be determined and noted. Where the locations of local drainage divides are known, an easy method of determining the drainage area is to show these local divides on the map and then planimeter the areas draining to each drain in the system. In some cases it may be necessary to make instrumental surveys to determine drainage areas. The above procedure is illustrated by the sketch map shown as Figure 7.6. The total area drained by the system is 122 acres, and the three laterals; namely, lateral 0.2, lateral 0.6 and lateral 0.8, drain areas of 13, 5, and 21 acres respectively. At the point of junction of two drains the shortest drain is always designated as the lateral.

Drainage Coefficients. The next step is the selection of the proper drainage coefficients. A drainage coefficient is the rate of runoff to provide a specified degree of drainage with regard to the existing climate, topography, land use and soils, and is developed from local experience.

In the design of small drainage systems the rate of removal per unit area for relatively flat non-irrigated drainage areas can be selected from the appropriate curves shown in Figures 7.7 and 7.8. Curves A, B, C and D, Figure 7.7, are used in the more humid areas of Kansas, Nebraska, and South Dakota. The S and M curves, Figure 7.8, are used in eastern North Dakota. Local drainage guides should be developed and used as a guide to depth, spacing, etc.

If the drainage area has a varied topography which requires determination of capacity from two or more curves which are to be combined to arrive at a capacity for the main outlet, the method of equivalent areas can be used; generally such problems should be referred to an Engineering Specialist familiar with the procedure outlined in Section 16, National Handbook on Drainage.

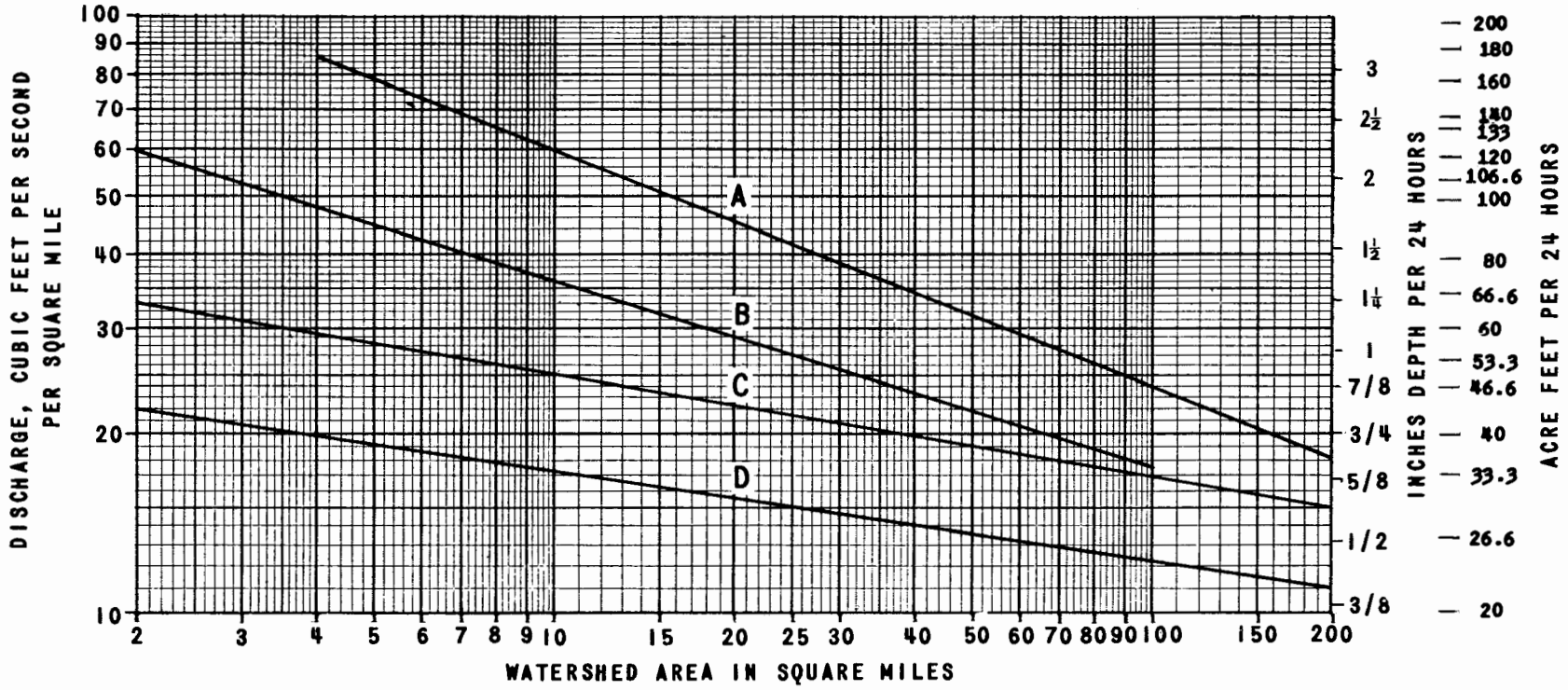
In irrigated areas and in relatively flat areas of Montana, western North Dakota, Wyoming and Colorado the rate of removal of runoff from precipitation is computed by the formula $Q = CM \times \frac{2}{6}$ following the procedure



DRAIN	D.A ACRES
MAIN DRAIN	
SECTION- A	19
" B	42
" C	11
" D	11
LAT.- 0.2	13
LAT.- 0.6	5
LAT.- 0.8	21
TOTAL	122

Figure 7.6

DRAINAGE COEFFICIENT CURVES FOR NORTHERN HUMID AREAS



USE OF CURVES FOR NORTHERN HUMID AREAS

Curve A - For good protection from overflow (not maximum flood run-off).

Curve B - For excellent drainage.

Curve C - For good agricultural drainage; basic drainage curve for grain crops.

Curve D - For fair agricultural drainage and drainage improved pastures.

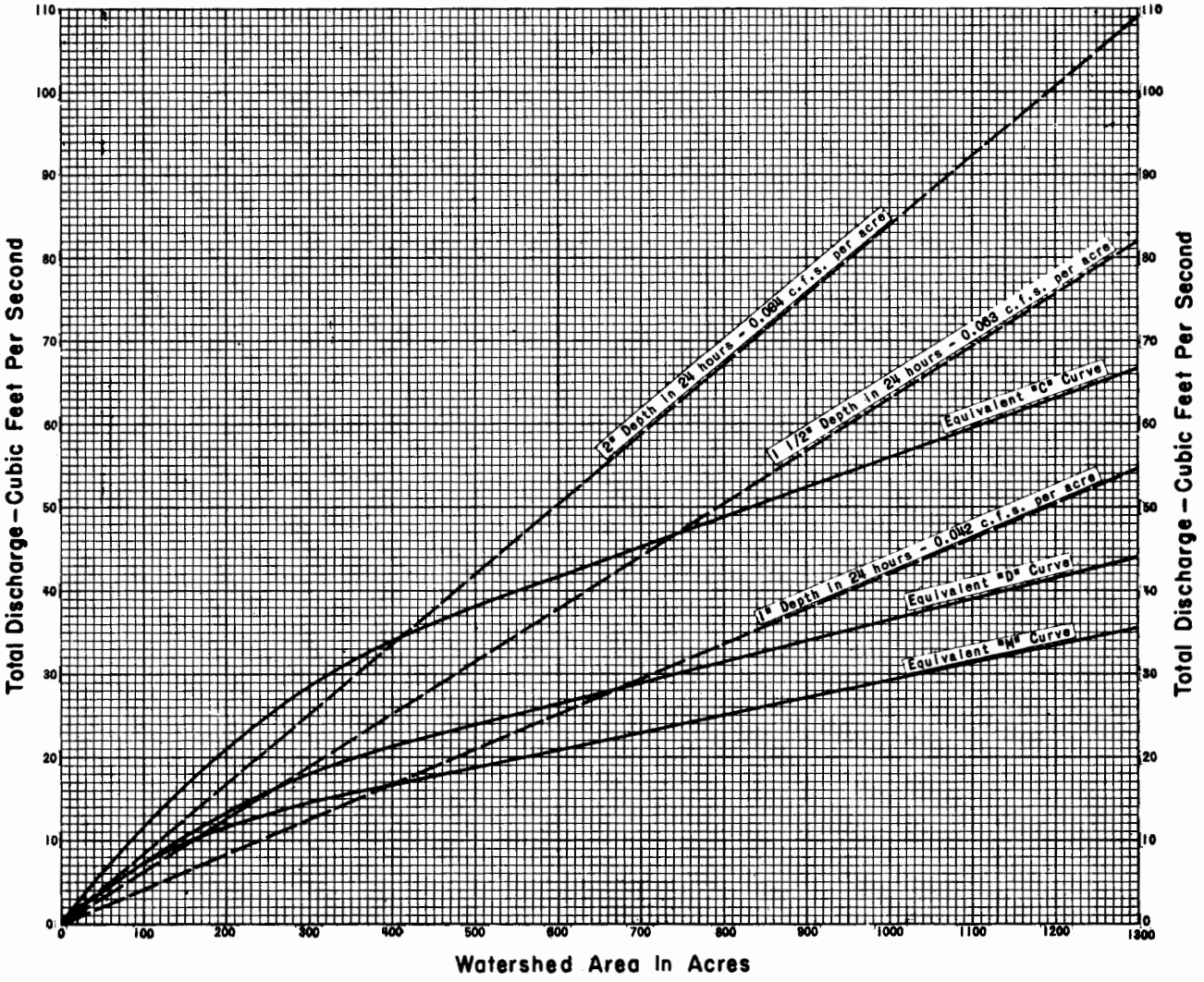
Watershed area to be determined above each section of the ditch for which capacity is to be computed. Applicable only to flat watershed areas having average slope less than 25 feet per mile.

REFERENCE: These curves, developed by John G. Sutton, published in the article, "Hydraulics of Open Ditches", Agr. Eng. Vol. No. 5, 1939.

Figure 7.7

DRAINAGE COEFFICIENT CURVES FOR NORTHERN HUMID AREAS

For Drainage Areas Less Than Two Square Miles


Total Discharge – Cubic Feet Per Second
Total Discharge – Cubic Feet Per Second
2" Depth in 24 hours – 0.084 c.f.s. per acre
1 1/2" Depth in 24 hours – 0.063 c.f.s. per acre
1" Depth in 24 hours – 0.042 c.f.s. per acre
Equivalent "C" Curve
Equivalent "D" Curve
Equivalent "M" Curve
Watershed Area In Acres

Explanation of Curves + C – For good agricultural drainage where the slope of the watershed exceeds 25 feet per mile.
D – For good agricultural drainage where the greater portion of the watershed does not slope more than 25 feet per mile.
M – For fair agricultural drainage in Red River Valley, North Dakota.

Continuation of Sutton C, D and M Drainage Run-Off Curves for watershed areas of less than two square miles.

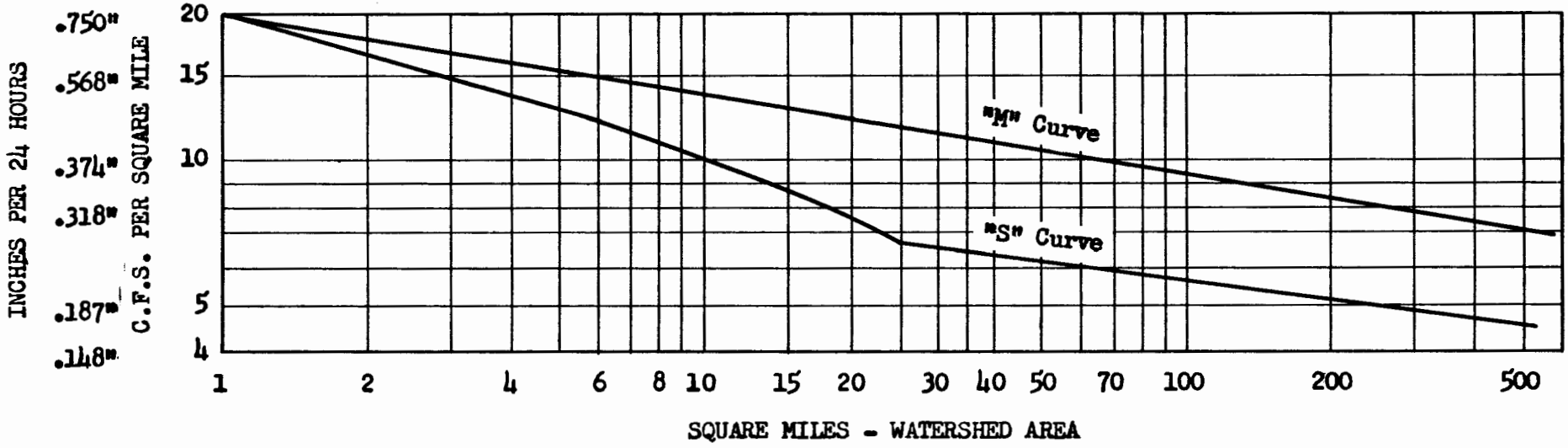
DRAINAGE COEFFICIENTS
May 14, 1945

Figure 7.7-1

DRAINAGE STANDARDS

Soil Conservation Service

Drainage Coefficients for Red River Valley, Minnesota - North Dakota



Note:

"M" curve should be used for conditions producing high rates of runoff including: steep slopes, impervious soils, crops requiring better drainage, and areas having intensely developed systems of Farm Drainage.

"S" curve should be used for conditions producing small rates of runoff which may include: flat slopes, pervious soils, crops requiring ordinary drainage, and areas with least development of Farm Drainage Systems.

Figure 7.8

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients (cont'd)

outlined in Section 16, National Handbook on Drainage. The rate of removal as specified by curves A, B, C and D is satisfactory for this determination on most of the ordinary drainage performed on irrigated farms. The runoff from irrigation waste water must also be calculated and added to the above calculations to arrive at the total ditch capacity. The amount to be added should be at least 15 percent of the rated capacity of irrigation laterals serving the area for light soils, while for heavy soils it should be 30 percent.

For steep areas hydrologic computations for surface runoff must be made as explained in Part 3 of this Handbook. In this case the ditch is designed to handle peak flood flow on some predetermined frequency rather than to provide for a rate of removal which would prevent crop damage.

After the drainage area has been delineated and the proper drainage coefficient selected, the ditch capacity must be computed for various reaches of the ditch by multiplying the drainage coefficient by the drainage area above the point in question. The following example explains this procedure:

Example. Assume a single surface drain 500 feet in length that drains a total area of 200 acres. Assume that a uniform drainage coefficient of 25 c.f.s. per square mile has been selected. The design flow at the outlet will be $\frac{200}{640} \times 25 = 7.8$ c.f.s.

Assume further that at the midpoint of the drain or at station 2 + 50 that the drainage area above this point is 80 acres. The design flow at this point will be $\frac{80}{640} \times 25 = 3.1$ c.f.s.

It is obvious from this example that the design flow will be different at different points within the system depending upon the drainage area served. It is also obvious that the size and capacity of the drain must vary at different points in relation to the drainage area. In drainage practice the size and capacity of the drain is not generally changed unless there is a significant change in the design flow, sufficient to change the bottom width of the drain by the amount of at least one foot. In small drains flowing less than 10 c.f.s. this rule is generally ignored as the type of construction equipment available may not be adjustable to these minor changes in ditch size.

The design flow should be computed for all critical points in the system prior to attempting to select cross sections for the ditch. The critical points where design flow should be computed are usually obvious on inspection. They are the points where laterals, natural side drainages, road ditches, etc. join. In cases where there are long reaches of drain with no contributing laterals, it may be necessary to break these up into sections and to compute design flows for each section. This is a "cut and try" method to determine if the change in design flow is sufficient to warrant a change in the ditch cross section.

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients - Example (cont'd)

In those cases where two drains with approximately the same size drainage area join together, it is necessary to increase the size of the main drain below this junction. This is necessary as it is quite probable that the two drains may both flow full at the same time and thereby concentrate the flow immediately below their junction. The "20-40 rule" as described in detail in Section 16, National Engineering Handbook, has been developed to give guidance in these particular situations. Briefly, this rule states that if the smaller of the two adjoining drains has a drainage area less than 20 percent of the total drainage area immediately below the point of junction, it should not be considered as significant in concentrating the flow at that point. Conversely, if the smaller drain has a drainage area 40 to 50 percent of the total drainage area immediately below the point of junction, it should be considered as significant in concentrating the flow at that point. In this latter case, the design flows as computed for each drain separately should be added together to determine the design flow immediately below the junction.

The next step in design is establishing the hydraulic gradient. The hydraulic gradient is the water surface or flow-line in any open conduit discharging at a specified rate. The hydraulic gradient is usually denoted by a small letter (s) in most hydraulic formulae and is expressed in fall or gradient in feet per foot. For example, a drain 800 feet in length has a total fall or difference in water surface elevation of 3.6 feet. The hydraulic gradient is:

$$s = \frac{3.6}{800} = 0.0045$$

The hydraulic gradient can be adjusted vertically by varying the depth, side slopes, or bottom width of the drain.

In drainage practice the maximum elevation of the hydraulic gradient is usually governed by the topography. If the flow line is above natural ground surface at any point along the route of the drain, flooding of the adjacent areas will occur. If, for other reasons, it is desirable to maintain the hydraulic gradient above ground level at certain points, dikes or levees may be constructed to prevent flooding of these areas. In some cases, minor flooding along the route of the drain may not be objectionable, and it might be tolerated. Whether or not flooding can be permitted depends primarily on land use and the crops grown. In design work, the governing rule is to keep the flow line about one foot below the lowest point of the ground surface on large drains. On small farm drains one-half foot is adequate.

At the time that profiles for the proposed drains are plotted, the hydraulic gradient should be located and drawn on the profile sheet in accordance with the previous discussion. The hydraulic gradient line should be as smooth and straight as possible and should never have sharp breaks or drops. Where it is necessary to change the slope of the hydraulic gradient

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients - Example (cont'd)

the change should be as gradual as possible. Often it is desirable to change grade at two or more locations in order to avoid making any large change at any one point.

Prior to attempting to select the size and shape of drain required for any given set of conditions, the design flow and the slope of the hydraulic gradient must be known. In addition, a coefficient of roughness usually denoted by small letter (n) must be selected. The coefficient of roughness is a physical expression of the condition of the side slopes and the ditch bottom for use in hydraulic formulae. The value of (n), the coefficient of roughness, for open drain ditches excavated in natural earth varies from 0.02 to 0.05 depending largely on the shape of the ditch. The following tabulation should be used as a guide for selecting the coefficient of roughness for small drains:

Shape Ditch	Coefficient of Roughness
Wide - Shallow	0.050
Average	0.040
Narrow - Deep	0.030

In most cases, the value of (n) equals 0.04 will be satisfactory for small ditches discharging less than 40 c.f.s.

The recommended side slopes should be based on local conditions. The side slopes on old ditches in similar soil types should be examined to determine stability.

The recommended steepest side slopes which should be used for ordinary conditions, unless otherwise specified, are as follows:

SOIL	SIDE SLOPES
Loam	2:1
Clay	1½:1
Peat, muck, sand, and loess soils	1:1
Field lateral ditches for silt, clay and muck	¼:1

Maintenance requirements often justify flat side slopes, especially for shallow ditches. Ditchbanks cannot be mowed or farmed safely with a wheel-type farm tractor on slopes steeper than 4:1. Crawler-type tractors may be used on 3:1 side slopes if dry. Special mowers which travel the ditch berm or bottom can mow slopes as steep as 1:1.

In many locations, especially in western irrigated areas, deep ditches require so much right-of-way that ditchbanks need to be constructed with as steep side slopes as possible to conserve land. Such ditches may justify

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients (cont'd)

an on-site study to determine the natural angle of repose of the soil, as well as to observe old ditches, so that stable side slopes can be determined.

The ideal velocity for drainage ditches is ordinarily from 2½ to 4 feet per second. Below 2½ feet per second sedimentation occurs, especially after vegetation becomes established. Within the range of 2½ to 4 feet per second some erosion of the ditch may occur after construction, but in most soils the ditch section stabilizes in a few years. Much sediment is carried through ditches having these velocity ranges. For ditches on non-erosive grades the channel with the largest hydraulic radius possible to obtain the highest design velocities should be used.

The maximum safe velocity is governed by the type of soil. The velocity at bank-full stage for flood flows is greater than for drainage flow. This should be checked. Some decrease in the design velocity may be obtained by making a ditch section wider and shallower or by adjusting the hydraulic gradient. If safe velocities cannot be obtained by these methods, vegetative treatment, drop spillways, culverts, or structures to control grade should be used.

When unusual accelerated watershed erosion, ditchbank erosion, or rapid rates of sedimentation affect drainage design, a competent geologist should be consulted.

Fortier and Scobey 1/ worked out limiting velocities for aged straight channels, (See Figure 7.9). The values for water transporting colloidal silts, Column 3, applies mostly to drainage ditches.

On ditches where the excavated earth is placed in spoilbanks, berms should be provided.

Adequate berms are required to:

(1) Provide roadways for maintenance equipment.
(2) Eliminate the need for moving spoil banks in future operations.
(3) Provide for work areas and facilitate spoil-bank spreading.
(4) Prevent excavated material from washing or rolling back into ditches.
(5) Lessen sloughing of ditchbanks caused by heavy bank loads too near the edge of the ditchbanks.

Usually a 10-foot berm will meet all requirements for ditches not over 6 to 8 feet deep, where the spoil banks are smoothed; and 15-foot berms will meet the requirements for deeper ditches.

1/ Samuel Fortier and Fred C. Scobey, Transitions ASCE, Vol. 89, page 955, 1926.

PERMISSIBLE CANAL VELOCITIES

Original material excavated for canal (1)	Clear Water, no detritus (2)	Velocity, in feet per second, after aging, of canals carrying: Water transporting colloidal silt (3)	Water transporting non-colloidal silts, sands, gravels, or rock fragments (4)
Fine sand (non-colloidal)	1.50	2.50	1.50
Sandy loam (non-colloidal)	1.75	2.50	2.00
Silt loam (non-colloidal)	2.00	3.00	2.00
Alluvial silts when non-colloidal	2.00	3.50	2.00
Ordinary firm loam	2.50	3.50	2.25
Volcanic ash	2.50	3.50	2.00
Fine gravel	2.50	5.00	3.75
Stiff clay (very colloidal)	3.75	5.00	3.00
Graded, loam to cobbles when non-colloidal	3.75	5.00	5.00
Alluvial silts when colloidal	3.75	5.00	3.00
Graded, silt to cobbles, when colloidal	4.00	5.50	5.00
Coarse gravel (non-colloidal)	4.00	6.00	6.50
Cobbles and shingles	5.00	5.50	6.50
Shales and hardpans	6.00	6.00	5.00

Figure 7.9

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients - Example (cont'd)

On many ditches where a minimum width berm is used to conserve land, or where a roadway is not needed along both berms, or where the spoil banks will be smoothed, maintenance work may be done from the top or side of the spoil banks. The width of one or both berms may be decreased consistent with above requirements.

The following minimum berm widths should be used unless otherwise specified:

Ditch Depths	Minimum Berms
2 - 4 feet	4.0 feet
4 - 6 feet	6.0 feet
6 - 8 feet	10.0 feet
Over 8 feet	15.0 feet

Where high velocities may enlarge the ditch or when the ditch is in marshy, peat, or other unstable soil, the berm width should be increased according to the particular requirements.

In establishing the width of berm, disposition of the spoil bank should be considered. The best use of the spoil and how far it can be spread are determined by the type of excavated soil, the adjacent land use, the need for roads, and the maintenance method employed. In some locations spoil banks can be spread and used to good advantage for roads.

In humid areas, the spoil banks usually should be leveled so they can be cultivated or kept in hay or pasture. A finished spoil bank should have side slopes of not less than 4:1, and slopes of 8:1 or flatter are desirable for pastured and cultivated fields. The spoil should be spread away from the ditch and should be left so ordinary farm equipment may operate over the spoil.

Spoil banks should not be leveled where infertile soils, rock, gravel, or irrigation requirements do not permit cultivation of spoil banks, or where they will be covered with timber or brush. Where not leveled, the spoil bank should be in as small a right-of-way as possible consistent with berm requirements and side slopes may be as steep as the soil permits.

Where unproductive soils occur at lower depths in large ditches, the good soil should be segregated during construction and utilized. Fertile spoil may be used for land grading and smoothing or for land leveling in adjacent fields.

Safe entry of surface water through the spoil into the ditch should be provided. In placing and spreading the spoil, points of entry and type of inlet structure to be used should be determined.

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients - Example (cont'd)

Drainage ditches should be designed to provide a ditch section that will pass the design flow throughout the length of the ditch. The crest of the water or flow-line in the ditch should be sufficiently below the elevation of the land surface to provide good drainage. Drainage coefficients and other design criteria should be determined as previously discussed. The grade of the ditch bottom may have a value different than the hydraulic gradient or flow-line as the ditch bottom is not always parallel to it.

Manning's formula is used for open ditch design because of its accuracy, simplicity, and because of the large number of charts and tables available for solution. The Manning Formula is usually written as follows:

$$V = \frac{1.486}{n} r^{2/3} s^{1/2}$$

Where

V = the velocity in feet per second
r = the hydraulic radius
s = the hydraulic gradient in feet per foot
n = the coefficient of roughness

The velocity of flow as computed by this formula can be multiplied by the cross sectional area of the ditch to determine the capacity of the ditch. This is given by the following formula:

$$Q = AV$$

Where

Q = the capacity in c.f.s.
A = the cross sectional area of the ditch in square feet
V = the velocity in feet per second

In order to simplify the use of these equations, tables are included in Part 16, Hydraulics, of this handbook. These tables cover a range of conditions which should be adequate for the design of small open drains. In order to illustrate the design procedures discussed and the use of the tables for solution of Mannings' Formula, the following example is given:

Example. Design a ditch cross section for a section of ditch as illustrated in Figure 7.10. Assume in this case that the flow-line will be one foot below the ground surface. Assume the following given conditions:

(1) The slope of the hydraulic gradient (s) = 0.001
(2) The coefficient of roughness (n) = 0.04
(3) A sandy loam soil, side slopes = 2 to 1
(4) The design flow (Q) = 23 c.f.s.

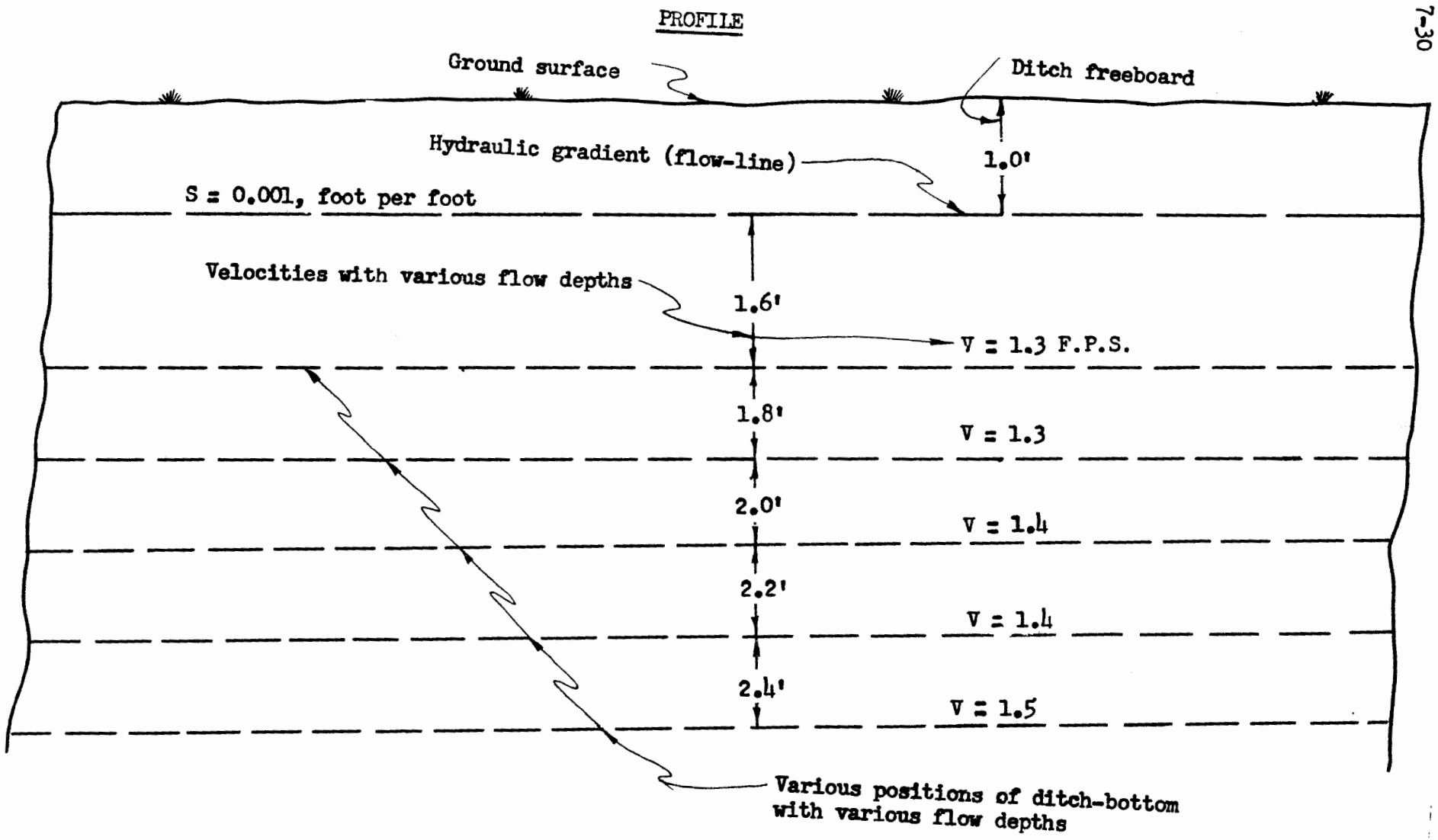

PROFILE
Ground surface
Ditch freeboard
Hydraulic gradient (flow-line)
1.0'
S = 0.001, foot per foot
Velocities with various flow depths
1.6'
V = 1.3 F.P.S.
1.8'
V = 1.3
2.0'
V = 1.4
2.2'
V = 1.4
2.4'
V = 1.5
Various positions of ditch-bottom
with various flow depths

Figure 7.10

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients - Example (cont'd)

Referring to the Discharge Tables for Trapezoidal Ditches (Part 16) for side slopes of 2 to 1, find the column headed "s = 0.001." An inspection of this column shows that there are different ditch cross sections with different bottom widths and depths that have a required capacity of 23 c.f.s. These are listed in the following tabulation taken from the table. The bottom width is always given in even feet. When the design discharge falls between given bottom widths in even feet, use the higher value:

Bottom Width (Feet)	Flow Depth (Feet)	Cubic Yards per 100 Lin. Ft.	Capacity cfs	Ditch Velocity in Feet Per. Sec.
8	1.6	65.6	23.5	1.3
6	1.8	63.5	23.4	1.3
*5	2.0	66.0	24.9	1.4
4	2.2	67.8	26.1	1.4
2	2.4	59.9	24.0	1.5

*Interpreted to next even foot of bottom width.

It is obvious from this tabulation that the designer has a choice of five cross sections from which to choose. The next consideration should be the velocity of flow. Referring to Figure 7.9, it will be noted that the maximum permissible velocity for ditches excavated in sandy loam material is two feet per second. This is higher than the highest velocity for any of the five cross sections listed; therefore, the high velocity is not a limiting factor in this particular case. As stated previously, the most desirable range of velocity for open ditches is from 2½ to 4 feet per second provided that the maximum permissible velocity for the particular soil type is not exceeded. In the case of this example, it would be desirable to design for the highest velocity (1.5 feet per second) provided that it is possible to have the corresponding flow depth of 2.4 feet. The next consideration should be the depth of the ditch. The depth below ground surface is the sum of the freeboard plus the flow depth. At any point within the system, there must be some grade in the ditch bottom to remove flows less than the design flow.

Where drains cross state, county, or private roads, it is necessary to provide culverts. The problem in design is to determine the proper size culvert to use in each case. Culverts may be metal, concrete, vitrified clay tile or fiber tile and are rated according to their inside diameter given in inches.

The cross sectional areas of culverts are usually less than the cross sectional area of the ditch in which they are placed. In order for the same quantity of water to pass through both ditch and culvert, the

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients - Example (cont'd)

velocity through the culvert must be greater than the velocity in the ditch. These relationships are expressed in the formula:

$$Q = AV$$

It is obvious that if the cross sectional area of the culvert is less than the cross sectional area of the ditch, the velocity in the culvert must be greater. The only way that the velocity through the culvert can be increased is to increase the head on the culvert. This is often referred to as "heading up at culverts" and simply means that the flow depth at the invert of the culvert will increase until the capacity of the culvert equals the capacity of the ditch. The designer must choose the size of culvert that will function with a permissible amount of heading-up. Figure 7.11 gives the discharge in c.f.s. for various sized culverts with various heads. This table has been prepared for corrugated metal culverts for submerged outlets and a length of 30 feet, which is about the usual length required for crossings on county or private roads. If the outlet has free discharge and will not be submerged, Figure 7.12 must be used. The following example is given to illustrate the use of Figure 7.11.

Example. Assume that an open drain with a design flow of 9 c.f.s. and a flow depth of 1.6 feet must cross a county road. Assume that a corrugated metal culvert is to be installed under the county road. Assume further that due to topographic conditions the outlet will be submerged to a depth of 0.1 foot and the maximum permissible heading up at the culvert cannot exceed 0.5 foot. (The water depth at the invert of the culvert = 1.6 feet + 0.5 foot = 2.1 feet.) The water depth at the outlet is 1.6 + 0.1 = 1.7 feet. Then 2.1 - 1.7 = 0.4. Referring to the left-hand column in Figure 7.11, find the value where "head on pipe in feet = 0.4 feet". From this point follow horizontally to the right until a capacity of 10 c.f.s. is equalled or exceeded. The value 9.72 c.f.s. will be found in the column headed 24" culvert. A 24" culvert will discharge 9.72 c.f.s. with a head of 0.4 feet. This head is the additional head required to force 9.72 c.f.s. through the culvert. Therefore, the total depth at the invert of the culvert will be the sum of flow depth without a culvert plus the additional head required by the culvert of 2.1 feet.

The hydraulics of structures is discussed in Section 5 of the National Engineering Handbook, and their design, in Section 6 of the same handbook. The following discussion of auxiliary structures covers the application and use of sample structures for open type surface drains. The structures usually required in open drains are culverts, bridges, chutes and drops. Detailed plans for a wide range of these structures is given in the section on Standard Structural Plans. In designing small structures in connection with open drains, these standard structural plans should be used in all cases where applicable, and where a special design is required the Area Engineer should be consulted.

CAPACITY OF CORRUGATED METAL PIPE (SUBMERGED OUTLET)
CULVERT FLOWING FULL - STRAIGHT ENDWALL ENTRANCE
CULVERT LENGTH 30.6 FEET
Values are in Cubic Feet per Second

Head on Pipe in Feet	12 inch	*15 inch	18 inch	*21 inch	24 inch	30 inch	*36 inch	*42 inch	*48 inch
.01	0.31	.52	.79	1.13	1.54	2.57	3.92	5.60	7.62
.02	.44	.73	1.12	1.60	2.17	3.64	5.55	7.92	10.8
.03	.54	.90	1.37	1.96	2.66	4.46	6.79	9.70	13.2
.04	.62	1.04	1.58	2.26	3.07	5.15	7.84	11.2	15.2
.05	.69	1.16	1.77	2.52	3.44	5.76	8.77	12.5	17.0
.06	.76	1.27	1.94	2.77	3.76	6.30	9.61	13.7	18.7
.07	.82	1.37	2.09	2.99	4.07	6.82	10.4	14.8	20.2
.08	.88	1.47	2.24	3.19	4.35	7.28	11.1	15.8	21.5
.09	.93	1.56	2.38	3.39	4.61	7.72	11.8	16.8	22.9
.1	.98	1.64	2.50	3.57	4.86	8.14	12.4	17.7	24.1
.2	1.39	2.32	3.54	5.05	6.87	11.5	17.5	25.0	34.1
.3	1.70	2.84	4.33	6.18	8.42	14.1	21.5	30.7	41.8
.4	1.96	3.28	5.00	7.14	9.72	16.3	24.8	35.4	48.2
.5	2.19	3.67	5.59	7.98	10.9	18.2	27.7	39.6	53.9
.6	2.40	4.02	6.13	8.75	11.9	19.9	30.4	43.4	59.1
.7	2.59	4.34	6.62	9.45	12.9	21.5	32.8	46.9	63.8
.8	2.77	4.64	7.07	10.1	13.8	23.0	35.1	50.1	68.2
.9	2.94	4.92	7.51	10.7	14.6	24.4	37.2	53.1	72.3
1.0	3.10	5.19	7.91	11.3	15.4	25.7	39.2	56.0	76.2
1.2	3.40	5.69	8.66	12.4	16.8	28.2	43.0	61.3	83.5
1.4	3.67	6.14	9.36	13.4	18.2	30.5	46.4	66.3	90.2
1.6	3.92	6.57	10.00	14.3	19.4	32.6	49.6	70.8	96.4
1.8	4.16	6.96	10.60	15.2	20.6	34.5	52.6	75.1	102.0
2.0	4.38	7.34	11.20	16.0	21.7	36.4	55.5	79.2	108.
2.2	4.60	7.70	11.74	16.8	22.8	38.2	58.2	83.1	113.
2.4	4.80	8.04	12.25	17.5	23.8	39.9	60.8	86.8	118.
2.6	5.00	8.37	12.81	18.2	24.8	41.7	63.0	90.3	123.
2.8	5.19	8.69	13.24	18.9	25.7	43.1	65.6	93.7	128.
3.0	5.37	8.99	13.70	19.6	26.6	44.6	67.9	97.0	132.
3.2	5.55	9.29	14.26	20.2	27.5	46.1	70.2	100.2	136.
3.4	5.72	9.57	14.60	20.8	28.4	47.5	72.3	103.5	141.
3.5	5.80	9.71	14.80	21.1	28.8	48.2	73.4	105.0	143.

NOTE: This table is based on the formula $Q = 3.10\ D^{2.31}H^{0.50}$ for corrugated pipe in which Q = discharge in cubic feet per sec., D = diameter of pipe in feet, and H = head on pipe in feet = difference in elevation of water surface at inlet and outlet ends.

*No experiments made on these sizes - quantity computed by formula.

This capacity table is compiled from figures obtained through a series of tests made by the Bureau of Public Roads at the Hydraulic Testing Plant of the University of Iowa. Note that capacities are for 30.6 ft. length pipe.

The figures underlined are for velocities of approx. 2, 4, and 6 ft. per second, reading downwards.

Taken from "Handbook of Water Control" - Hardesty Co.

Figure 7.11

CORRUGATED PIPE CULVERT - FREE OUTLET

CORRUGATED PIPE CULVERTS - Free Outlet
With Water Surface at Inlet Same Elevation as Top of Pipe, and Outlet Unsubmerged
Values Are in Cubic Feet Per Second

Slope in	DIAMETER OF PIPE, IN INCHES																				
Per Cent	8	10	12	15	18	21	24	30	36	42	48	54	60	66	72	78	84	90	96	108	120
.1	0.2	0.4	0.6	1.3	2.1	3.3	4.7	8	12	20	25	36	47	67	85	110	130	160	190	270	330
.2	0.3	0.6	1.0	2.0	3.1	4.7	6.8	12	19	30	42	57	77	100	130	160	190	230	270	380	500
.3	0.4	0.8	1.3	2.4	3.9	5.9	8.3	15	25	37	53	72	97	120	150	190	230	280	330	450	600
.4	0.5	0.9	1.5	2.8	4.4	6.8	9.5	17	28	42	62	83	110	140	180	220	270	320	380	510	670
.5	0.6	1.0	1.7	3.0	4.9	7.5	10	19	31	46	68	90	120	150	190	240	290	340	410	560	730
.6	0.6	1.1	1.9	3.3	5.4	8.1	11	21	33	50	72	97	130	160	210	250	300	360	430	580	770
.8	0.8	1.2	2.1	3.7	6.1	9.0	13	23	37	55	77	100	140	180	220	270	320	390	460	620	**810**
1.0	0.8	1.4	2.3	4.0	6.5	9.6	14	24	39	57	80	**110**	140	180	**230**	**280**	**330**	**400**	**470**	**630**	810
1.2	0.8	1.5	2.4	4.3	6.8	10	14	25	**40**	**59**	**82**	110	**150**	**190**	230	280	330	400	470	630	810
1.4	**0.9**	**1.6**	2.5	4.4	7.0	10	**15**	25	40	59	**83**	110	150	190	230	280	330	400	470	630	810
1.6	0.9	1.6	**2.6**	4.5	**7.1**	10	15	**26**	40	59	83	110	150	190	230	280	330	400	470	630	810
1.8	0.9	1.6	2.6	**4.6**	7.1	**11**	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.0	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.2	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.4	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810

Note: The values in bold face type indicate discharge at the approximate "critical slope", beyond which the discharge remains constant for any given size culvert.

The "stairs" of heavy horizontal lines beginning at the upper left and reading downward and to the right indicate approximate velocities of 2, 4, 6, 8, and 10 feet per second.

Taken from: "Handbook of Water Control" Hardesty Co.

Figure 7.12

2. DESIGN (CONT'D)

Surface Drainage (cont'd)

Drainage Coefficients - Example (cont'd)

The Discharge Tables for Trapezoidal Ditches (Part 16) give the yardage in the ditch below the flow-line or water line in cubic yards per hundred lineal feet of ditch. Obviously, this is not the yardage of excavation as it is computed using the flow depth rather than the total depth of the ditch. These tables can be used to estimate the yardage of excavation by adding the freeboard to the flow depth and using this value as the depth value in the table.

The following example illustrates this method:

Example. Assume that at a certain given point on a ditch the flow depth is 1.4 feet, the bottom width is 4 feet, side slopes are 2:1 slope, and that the freeboard is 1.2 feet. The total depth of the ditch below ground surface will be equal to the flow depth plus the freeboard.

1.4 feet + 1.2 feet = 2.6 feet

Using the total depth of 2.6 feet, find the cubic yards per hundred feet of lineal ditch as follows:

In these same tables, labeled 2:1 side slopes, locate the horizontal line where the flow depth is given as 2.6 feet and the bottom width as 4 feet. The cubic yards per hundred lineal feet are equal to 87.8 cubic yards. This is the yardage of excavation for 100 lineal feet of ditch. This method is only approximate as it is based on the assumption that all cross sections are level sections which is seldom true, but this table is useful in making rapid estimates. Final yardage computations should be made using the earthwork computation tables or "average-end-area-methods".

Subsurface Drainage

Subsurface drainage is defined as the removal and disposal of excess ground water which is causing a high water table condition. Investigations for subsurface drainage differ from those for surface drainage in that the emphasis should be placed on obtaining an understanding of ground water conditions and behavior.

Surveys. Surveys for subsurface drainage systems cover most of the items included in the surveys for surface drainage systems. In addition, these must include provision for obtaining more detailed information on ground water, subsoil and substrata conditions.

Topographic surveys for subsurface drainage should, as a general rule, be more detailed than for surface drainage. The reason for this is that it is necessary to correlate the relative elevations of water table levels and ground surface levels at various points throughout the area. The subject of topographic surveys and the preparation of topographic maps is

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Surveys (cont'd)

covered in Part I of this handbook. For purposes of subsurface drainage, experience has shown that topographic maps on a scale ranging from 100 to 660 feet per inch and with a contour interval of one-half foot to five feet are most satisfactory. There is no set rule for the scale and contour interval required on topographic maps for drainage planning as they must vary with the slope and land configuration to adequately show the surface topography. The map should be sufficiently large to show the necessary features clearly, but should not be so large as to be clumsy or difficult to work with. All significant cultural features such as building, fences, irrigation canals, roads, trails and surface drains should be shown on the map. Foreign drainage entering or crossing the area under consideration should be shown and the drainage area determined and noted on the map. This is especially important where open-type subsurface drains are to be used for both surface and subsurface drainage.

Soil surveys are normally available through Service channels for areas under consideration for drainage planning. If they are not available, it usually is possible to make arrangements to have such surveys prepared in advance of planning. In subsurface drainage work the chief concern is with subsoil and substrata materials rather than the so-called top soils which are considered as the root zone area ranging in depth from 1 to 24 inches. Top soil conditions determine land use and land values and in turn may dictate the economic feasibility of conservation measures including drainage. In the mechanics of analyzing drainage problems and planning drainage work the chief concern is with the texture and permeability of subsoil and substrata sediments below 5 feet which is the usual depth of borings made in connection with regular soil surveys.

Conditions of salinity and alkalinity are especially important in the drainage of irrigated lands in semi-arid regions. A very thorough treatment of the subject of saline and alkaline soils is given in Agricultural Handbook No. 60, entitled "Diagnosis and Improvement of Saline and Alkaline Soil" published by the U. S. Salinity Laboratory. In analyzing a drainage problem where soils are saline, saline-alkaline or non-saline-alkali, special attention must be given to the matter of reclamation through drainage. If conditions of salinity or alkalinity appear critical, the drainage engineer should seek the advice of a soil scientist prior to planning drainage works. Generally, soils that are saline-alkali or non-saline-alkali may, or may not, be reclaimable through leaching operations alone. Quite often chemical amendments must be added prior to leaching and when this is necessary a cost analysis must be made to evaluate economic feasibility in considering both the cost of drainage works and the cost for the additional chemical amendments that may be required.

In areas proposed for subsurface drainage, it is necessary to know subsoil and substrata conditions to a minimum depth of at least two feet below the proposed depth of any drain and preferably to a depth of two and one-half times the drain depth. Under average conditions 20 feet is considered

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Surveys (cont'd)

adequate in most areas. This depth is necessary to explore subsurface sediments and to determine the structure, texture, and permeability. Often the success or failure of subsurface drains is dependent upon the permeability of subsurface material below the bottom of the drain. This is especially true under artesian conditions where there is an upward movement of ground water.

The location and spacing of subsurface borings must be based largely on a knowledge of soils, local geology, and experience gained in a particular area. Borings must be spaced sufficiently close to enable the correlation of subsurface strata. In alluvial materials this spacing may have to be 100 feet or less and in more or less homogeneous residual soils a spacing of 1,000 feet or more may be satisfactory. In practical application the usual procedure is to select a spacing that is in excess of that thought necessary and then to supplement this spacing as conditions warrant on the basis of the information obtained. Subsurface borings should be located on a rectangular grid pattern and with a spacing as previously discussed. The rectangular grid pattern may be oriented in any convenient direction to fit the field. Usually it is made parallel to a prominent road or fence which is used as a base line. When the spacing has been established, guide stakes can be placed at the field boundaries and interior stakes can be sighted through.

It is highly important that accurate logs be kept for all subsurface borings that are made. Each boring should be given a number and a log should be prepared using that number for reference and identification. The log sheet in Part 2 of this handbook is considered adequate for drainage investigations and has been designed to reduce field notes and description to a minimum. In addition to the data as shown on the legend, it is always desirable to show the water table level, if any, at the time of boring.

The importance of obtaining adequate and accurate ground water data can not be overstressed as it is the basis for determining the type and size of subsurface drainage system to be constructed. Ground water information can be obtained by establishing and measuring water table levels in either observation wells or piezometers. The use of observation wells is usually the most practical method for small projects where special equipment is not available for establishing piezometers. Observation wells can be established by casing subsurface borings with some inexpensive and temporary casing which will last for at least one year. Any casing material that will serve to prevent sloughing of the hole is satisfactory. These casings might be second-hand iron pipe, wooden box casings, or down-spout pipe. The latter material has been used extensively and has many advantages such as lightness, ease of transportation and it can be cut in the field with an ordinary pair of tin-snips. If perforations are made, they can be made in the field with a punch and hammer. The casing for observation wells should be a minimum of one and one-half inch in diameter to prevent clogging and to facilitate making water table readings.

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Surveys (cont'd)

When the observation wells are established, the elevation of the ground surface at each well and the elevation of the top of casing for each well must be determined. Water table measurements should be made by measuring the distance from the top of casing to water levels in the well. This distance can be subtracted from the top of casing elevation to determine the actual water table elevation.

A simple device for measuring the depth to water in observation wells is a length of one-fourth inch plastic hose. The hose can be calibrated and marked in feet and tenths of feet and when lowered into the well casing, while blowing in the open end, it will bubble when the lower end of the hose touches the water surface. This hose is light and easy to carry and store, and will facilitate taking readings to the nearest tenth of a foot which is considered adequate.

Some tabular form should be used for recording water table readings. The number of each well should be listed and the elevation of the water table shown for each date that the wells have been measured. In most areas water table fluctuation will follow some fixed pattern. In non-irrigated areas water tables are generally highest in the spring of the year. In irrigated areas water table levels are generally highest in midsummer or early fall. The design of subsurface drains is based on lowering the water table to some predetermined level which will permit proper plant growth. In order to determine what the high water table level is in a particular area, it may be necessary to make several water table measurements covering a period of several months. For this reason, wells should be cased, maintained and measurements properly recorded. Water table measurements made once each thirty days are usually considered adequate. Measurements should be continued until the data indicates that the generally high water table level has been recorded.

Ground water data should be analyzed to determine the extent of the wet or affected area, the position and fluctuation of the water table level or piezometric surface in relation to the ground surface and to determine the direction of flow or movement of ground water. The depth to the water table at the location of each observation well should be plotted for the critical period (time of highest water table level) and lines delineating various depths to the water table should be drawn. The configuration described by these lines will outline the wet areas and will show their relative degree of wetness. Elevations of the water table level at the location of each observation well should be plotted for the critical period and from this data ground water contours can be drawn. Ground water flow or movement is always perpendicular to the ground water contours; therefore, the direction of flow is known.

Surface water disposal is often combined and cared for in subsurface drainage systems where open-type drains are used. This usually works out very satisfactorily as open subsurface drains are necessarily deep and

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Surveys (cont'd)

usually have ample capacity for surface water disposal in addition to ground water disposal. When drains are designed for dual purposes, their capacity or design flow should be the sum of surface runoff plus ground water flow. In actual practice, ground water flow is usually relatively small as compared to surface water runoff, and the maximum capacity of the drain is virtually the flow expected from surface runoff. In most cases, open subsurface drains will have ample capacity for surface runoff, but their design should always be checked to insure that the capacity is adequate for both surface and subsurface drainage.

Where covered-type or tile drains are used, they are seldom designed as dual purpose drains to care for both surface and subsurface drainage. The reason for this is that the necessary increase in tile size to care for surface water in addition to ground water would, in most cases, make the cost prohibitive. The usual procedure is to design a tile system for ground water disposal only and to plan a separate open ditch system for surface water disposal.

In irrigated areas drainage must be provided for the removal of irrigation waste water. If open-type subsurface drains are installed, it is usually a simple matter to dispose of waste water through the subsurface drainage system. Structural provisions must be made to convey waste water to the drain without causing erosion of the ditch banks. Drop or chute structures of various designs will serve this purpose. Pipe-drops installed through ditch banks are very satisfactory and are in common usage. Where covered-type of tile drains are employed as subsurface drains in irrigated areas, it may or may not, be desirable to use these for waste water disposal. The decision must be based on an analysis of the local conditions to determine the increase in tile size required and the additional cost must be weighed against the cost and inconvenience of separate surface drains. Generally, it is more economical to provide separate surface drains for waste water disposal.

Outlet conditions for surface drains have been discussed and these are applicable to subsurface drainage as well. As a general rule, subsurface drains should outlet one foot above the average stage or flow-line of perennial streams or rivers. During times of flood flow when the stream or river is at flood stage, water will back up into the lower portions of drains and render them temporarily ineffective. When this is the case, a stage hydrograph of the stream or river should be compiled for purposes of evaluating time and duration of backwater conditions. A study of the hydrograph in relation to crop damage may indicate the desirability of adjusting the outlet elevation. It is often desirable to install flap-gates or floodgates in the outlet to main streams to lessen temporary backwater damage. Flap-gates may also be necessary in the outlets of main laterals where they outlet near the lower end of the main drain.

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Design of Subsurface Drainage. The primary objective of subsurface drainage is to lower existing high water table levels. The removal and disposal of surface water and irrigation waste water in irrigated areas is a secondary consideration and may, or may not, be included in the subsurface drainage plan.

The results of many field observations indicate that water table levels within 6 feet or less from the ground surface may be damaging to plant growth. A depth of about 4 to 5 feet or less is considered as critical in most areas. The critical depth where serious damage occurs is dependent upon local conditions as to salinity, alkalinity, capillarity and the root zone depth of the crops grown. From a cost standpoint, 9 feet is considered about the maximum depth for open drains, and 5 feet for tile drains placed with a tiling machine. With the advent of tiling equipment capable of greater depth, this latter limitation will be removed.

One of the most difficult problems in connection with planning subsurface drainage work is to compile and analyze the information obtained from the subsurface drainage study. This is difficult because two major factors - mainly, subsurface sediments and ground water conditions - are not evident on visual inspection of the area. Some method must be developed whereby these conditions can be made evident through a graphical or statistical presentation. Numerous methods have been worked out by various individuals, and although each is different, all are developed to aid in formulating a mental picture of subsurface conditions. One way to accomplish this is to prepare a working map of the area showing topographic and ground water conditions. Soil, subsoil and substrata conditions may also be shown on the map, but is usually better to indicate these on a separate map or tabulation. Transparent overlays, each showing separate features are very helpful working tools. A base map showing cultural and topographic features can be prepared on regular drawing paper and overlays or transparent sheets may be added to show soil, subsoil, substrata and ground water conditions. Through this or some similar method a working map can be compiled showing the information and data needed.

As stated previously, it is necessary to have a clear picture of topographic, soil, subsoil, substrata, and ground water conditions and their relationships before attempting to plan a subsurface drainage system. Various methods and techniques have been developed to obtain a true picture of these conditions. One method which has been used with considerable success is to compile a working map to show this information in successive stages of development. The following is a discussion of such a method showing how a working map might be developed and used.

Figure 7.13 is a topographic map of a hypothetical irrigated farm containing 488 acres and subject to a high water table condition. Basically, this map shows the usual cultural features that would be mapped including the irrigation supply canal and surface contours which are shown on a five-foot vertical interval. This map will serve as a base map for the working map to be developed progressively in the following example.

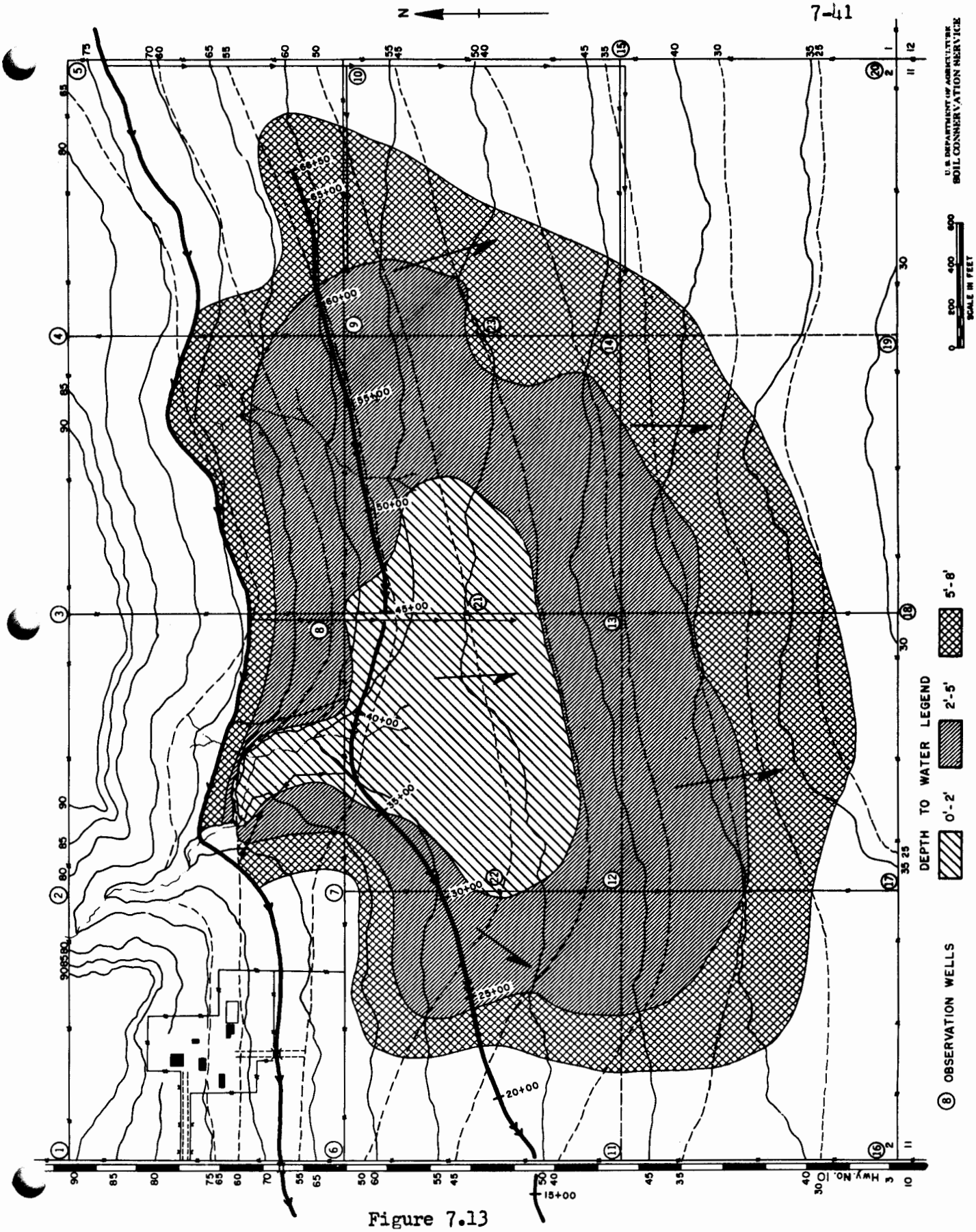

N
U.S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
SCALE IN FEET
0
400
800
DEPTH TO WATER LEGEND
0'-2'
2'-5'
5'-8'
OBSERVATION WELLS
Hwy. No. 10
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00
55+00
60+00
65+00

Figure 7.13

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Design of Subsurface Drainage (cont'd)

Figure 7.14 is a tabulation of ground water information and data obtained from water table measurements in 23 observation wells used in this example. The depth to the water table (distance from the ground surface to the water table level) and the water table in elevations reduced to a standard datum are shown for each well for the period of record May through September. From inspection it is obvious that the month of August, during which time 10 of the 23 wells showed their highest water table levels, is the critical month, or the month in which water table levels are generally high in this area. The information given for the month of August should be used for planning and design purposes as it represents the most severe high water table condition.

Referring to Figure 7.13, ground water information can be shown on the map as follows: The locations of the 23 observation wells are indicated by small circles with the well number shown in the circles. The elevation of the water table for the month of August as shown for each well in Figure 7.14 can be plotted on the map and from these ground water contours can be drawn. The ground water contours are shown on the map as dashed lines and have been drawn on five-foot vertical intervals to correspond in elevation with the surface contours. When this data is plotted and the location of the ground water contours determined, the hydraulic gradient of the water table surface and the direction of the ground water flow can be determined at any given point. The direction of ground water flow is always perpendicular, or at right angles, to the ground water contours and is indicated on the map by arrows as shown. In this particular example the ground water contours are on a five-foot vertical interval, and the average distance between contours is 500 feet; therefore, the slope of the water table is about 1 percent.

In addition to giving water table elevations, Figure 7.14 lists the "depth to water" in each observation well for the period of record. This is simply the depth from the ground surface to the water table level in each well. By plotting the minimum depth to water table regardless of the month in which it occurred, for the period of record, lines of delineation of depth to water table can be drawn. For this particular example the lines were drawn for the 2, 5, and 8-foot depths as shown on the map in Figure 7.13. This in effect, delineates areas where the range in depth to water table is from 0 to 2 feet, 2 to 5 feet, and 5 to 8 feet. These areas are shown by hatchure as indicated in the legend on the map. In this example, no attempt has been made to show depths 8 feet or more below the surface as this is not considered significant in agricultural drainage. In many areas a depth of less than 8 feet might not be considered significant.

The completed working map as shown in Figure 7.13 shows pictorially all of the information necessary for planning a drainage system except for the information on subsoil and substrata material. Usually it is not necessary to attempt to show this information on the working map; however,

OBSERVATION WELL DATA

	Elevation		May		June		July		August		September	
Well Number	Ground Surface	Top of Casing	Depth to Water Table	Water Table Elev.	Depth to Water Table	Water Table Elev.	Depth to Water Table	Water Table Elev.	Depth to Water Table	Water Table Elev.	Depth to Water Table	Water Table Elev.
1	94.3	96.8					(18.0)	(76.3)	19.1	75.2	20.1	74.2
2	78.2	81.1	(3.4)	(74.8)	11.2	67.0	8.4	69.8	10.2	68.0	10.8	67.4
3	93.7	95.7	(15.1)	78.6	15.8	(77.9)	19.1	74.6	18.0	75.7	20.0	73.7
4	84.0	87.1	16.0	68.0	16.1	67.9	(9.6)	(74.4)	12.6	71.4	15.1	68.9
5	76.8	78.6	12.8	64.0	(11.0)	(65.8)	11.6	65.2	11.9	64.9	11.6	65.2
6	62.7	64.7	13.6	49.1	(10.0)	(52.7)	11.0	51.7	10.8	51.9	10.1	52.6
7	62.0	64.6	14.8	47.2	12.1	49.9	9.5	52.5	(9.0)	(53.0)	12.2	49.8
8	61.3	63.8	7.2	54.1	3.9	57.4	3.1	58.2	(2.0)	(59.3)	4.1	57.2
9	58.4	60.1	8.0	50.4	6.0	52.4	5.0	53.4	(4.1)	(54.3)	6.3	52.1
10	57.6	58.2	13.1	44.5	11.9	45.7	(9.1)	(48.5)	(9.1)	(48.5)	11.4	46.2
11	46.5	48.4	11.8	34.7	10.2	36.3	9.8	36.7	9.3	37.2	(9.1)	(37.4)
12	46.0	48.6	6.3	39.7	5.1	40.9	4.2	41.8	(3.0)	(43.0)	4.5	41.5
13	43.9	45.8	5.1	38.8	4.2	39.7	3.8	40.1	(3.4)	(40.5)	3.8	40.1
14	44.2	46.6	8.6	35.6	8.1	36.1	(6.1)	(38.1)	7.3	36.9	7.0	37.2
15	44.1	46.2	12.4	31.7	10.8	33.3	(9.3)	(34.8)	9.6	34.5	10.6	33.5
16	37.8	39.6	11.7	26.1	10.1	27.7	11.2	26.6	10.0	27.8	(9.1)	(28.7)
17	35.6	37.0	10.8	24.8	9.8	25.8	9.3	26.3	9.2	26.4	(9.0)	(26.6)
18	29.8	32.1	11.9	17.9	10.6	19.2	10.1	19.7	9.5	20.3	(8.6)	(21.2)
19	29.1	31.6	11.8	17.3	10.8	18.3	11.8	17.3	11.0	18.1	(10.2)	(18.9)
20	33.0	35.4	18.6	14.4	17.2	15.8	13.6	19.4	(12.5)	(20.5)	14.1	18.9
21	49.0	51.4	6.0	43.0	6.1	42.9	3.8	45.2	(0.0)	(49.0)	4.0	45.0
22	52.5	55.0	6.1	46.4	5.6	46.9	2.3	50.2	(1.5)	(51.0)	4.0	48.5
23	50.5	52.6	7.4	43.1	7.8	42.7	5.8	44.7	(5.5)	(45.0)	6.1	44.4
			(2)		(2)		(5)		(10)		(5)	

Figure 7.14

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Design of Subsurface Drainage (cont'd)

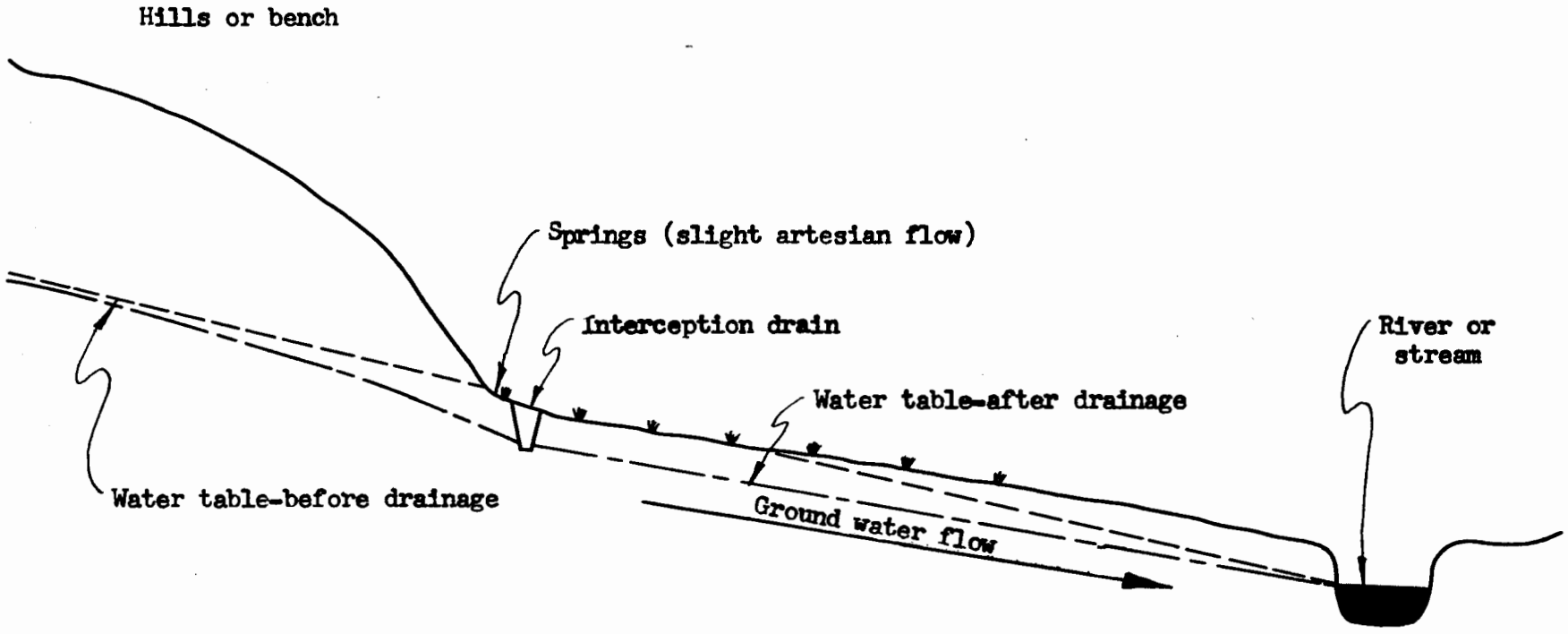
it might be shown by some pictorial method if thought necessary. Logs prepared on standard log sheets are easy to refer to for specific information on subsoil material at any particular point.

At this stage of development of the working map the type of drain or drains to be installed can be determined and the locations fixed within approximate limits on the working map. Referring again to Figure 7.13, it is obvious from the location of the wet area and the direction of ground water flow that the source of excess ground water is either from canal seepage or from irrigation losses within or immediately above the hatchured area. For purposes of this example it will be assumed that canal seepage has been investigated and found negligible and that the source of excess water is from general irrigation losses. Under this set of conditions and with a water table gradient of about one percent, an interception-type drain should be recommended. The drain should be located perpendicular to the direction of ground water flow and in a position near the upper edge of the wet or affected area. In such a location the interception drain will intercept the water now causing a high water table condition below it and will have some drawdown effect above the drain sufficient to lower the water table and relieve the wet area. The approximate location for such a drain is indicated by the heavy line with double arrows as shown on the map. In this example it must be assumed that subsoil materials are satisfactory for such a drain at this location. In the event that subsoil materials were highly variable over this field, the drain might be shifted up or down slope to a limited degree to place it in the most favorable position insofar as subsoil permeability is concerned.

The example illustrated depicts a set of conditions wherein an interception-type drain would be employed. A similar method of compiling and analyzing data would be applicable under conditions where a relief-type drain or drains would be used and the same approach is applicable to either irrigated or non-irrigated lands where the problem is one of a high water table condition.

Figures 7.14 through 7.21 are sketches of typical cross sections illustrating relief and interception-type drains located so as to correct a high water table conditior under different physical conditions.

Figure 7.15 illustrates an interception-type drain located at the base of hill land or at the base of a terrace or bench. This is a very common situation in major stream valley areas. Many investigations in similar areas have shown that wet or high water table areas usually occur near the base of the terrace and extend for a limited distance toward the river or stream. Ground water investigations of a situation of this kind usually disclose that the water table is approximately a straight line or a very flat curve extending from water surface in the stream to some distant point beneath the terrace bench. The wet area is existent because of an abrupt



Typical example - Interception drain at base of hill or terrace to intercept ground water flow to natural stream or river. Applicable in many large valleys with seeped lands near terrace or bench breaks. Either open or closed type drains.

Figure 7.15

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

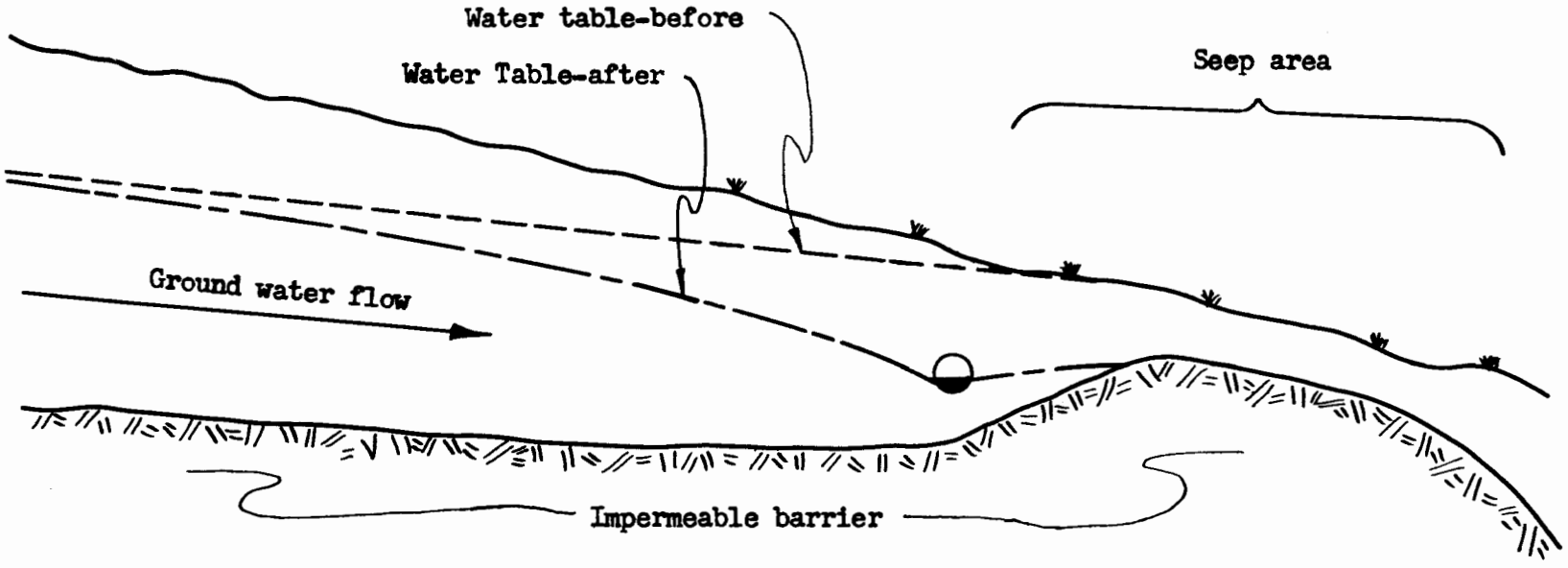
Design of Subsurface Drainage (cont'd)

change in topography at this point which brings the land surface near or in contact with the water table surface. The corrective measure as indicated is to lower the water table in this critical area through the installation of an interception drain. In situations of this kind where the drain may be located in an active floodplain area a closed-type drain should be used. If an open-type drain is used, there is danger that it may be captured by the stream during periods of flood flow and thus cause undesirable channel changes.

Figure 7.16 illustrates an interception-type drain located topographically above a constricting underground barrier of impermeable material. Under natural conditions, this barrier causes a "pinching off" of the aquifer and in turn causes the hydraulic gradient to "surface". This situation is common in alluvial floodplain areas where old channel changes have built up barriers of fine-grained sediments. This condition is difficult to detect and usually requires extensive subsoil explorations; however, the presence of an unexplainable wet area surrounded by dry area suggests such a nonconformity in subsoil material. In some instances where the barrier may be very narrow, it may be possible to construct one or several short relief-type drains through the barrier thereby lowering the water table above it.

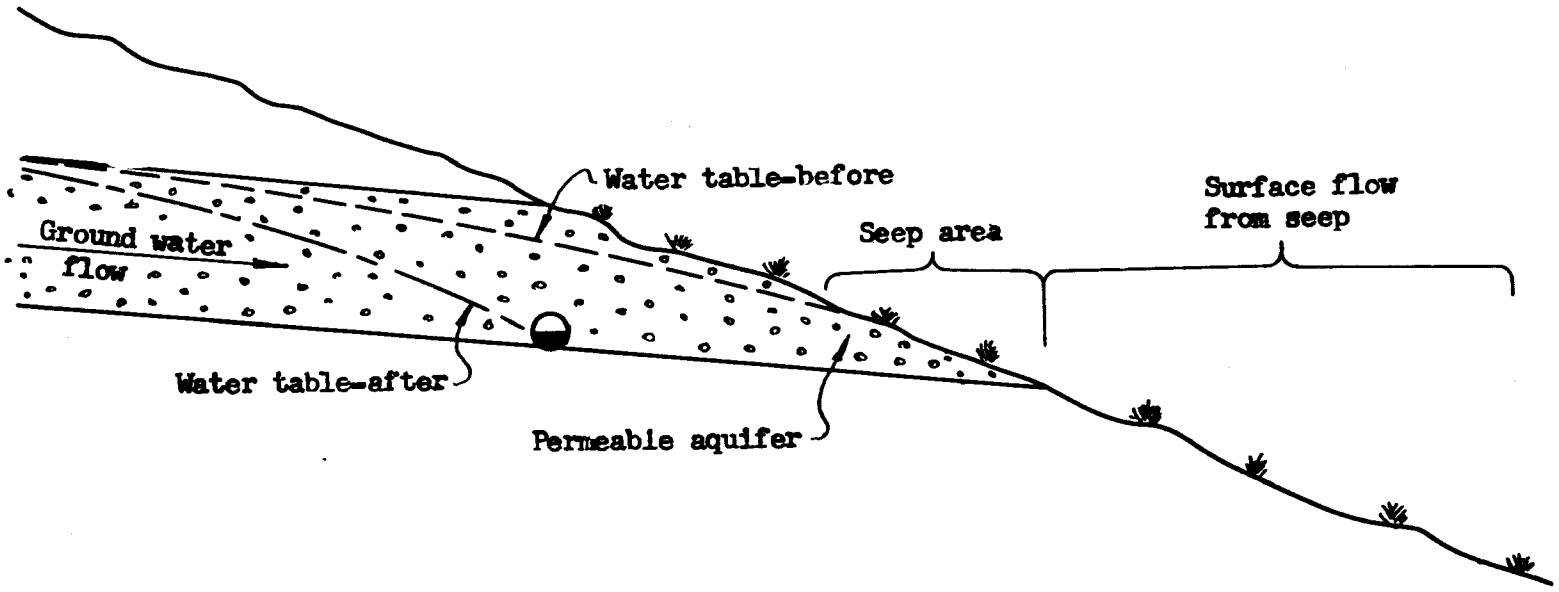
Figure 7.17 illustrates an interception drain located at the base of a permeable aquifer between layers of less permeable or nonpermeable material. The permeable layer outcrops causing a seep which may in turn affect a considerable area topographically below the outcrop. This situation may be common in sedimentary deposits that are highly stratified. Under natural conditions the permeable layer is usually carrying considerable ground water flow with a hydraulic gradient that intercepts the ground surface at some point in the outcrop area causing a natural seep. An interception-type drain should be located at the base of the permeable material to collect the flow from the aquifer and prevent seepage at the surface. The drain should be located at a point which will fix the depth of a permissible water table level consistent with soils and saline or alkali conditions.

Figure 7.18 illustrates an interception-type drain employing relief wells to lower a general high water table condition. The sketch is intended to show a condition where very slowly permeable subsoil and substrata materials with a depth of 20 to 30 feet are underlain by permeable sediments. Under natural conditions hydrostatic pressures are sufficient to maintain a water table level at or near the ground surface. Under these conditions it is not economically feasible to construct a drain with depths sufficient to tap the permeable material and a drain of less depth contained in very slowly permeable materials would not be very effective. By installing the deep interception drain (8 to 10 feet) with relief wells extending into the permeable materials, it is possible to lower the water table level by the amount of the effective head created. The effective



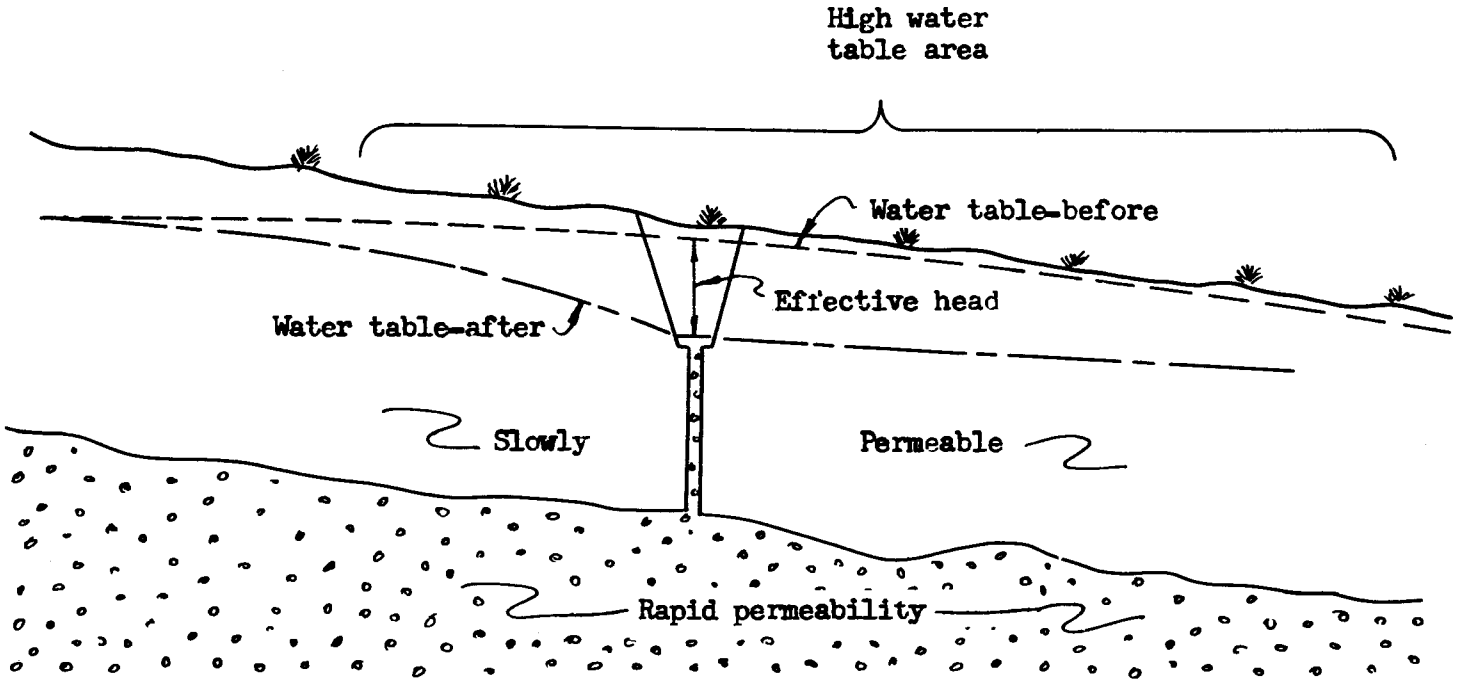
Typical example- Interception drain located above barrier to intercept ground water flow lowers the water table level and prevents seep. Drain may be either open or closed type.

Figure 7.16



Typical example - Interception type drain used to intercept ground water flow from permeable aquifer near point of outcrop. May use either open or closed type drain.

Figure 7.17



Typical example - Interception drain with relief well to tap permeable aquifer at depth too deep for direct contact. Applicable under special conditions where a good aquifer is known to be present and where the effective head is five feet or more. Closed type drain may be used.

Figure 7.16

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Design of Subsurface Drainage (cont'd)

head in this case is the difference in elevation between the water table level and the water surface in the drain. The operating head is the effective head less friction loss, entrance losses, etc., in the relief well. Practical experience has indicated that the effective head should be 5 feet or more before attempting this type of installation. The spacing of relief wells must be on a trial basis for an individual case. Relief wells should be added until hydrostatic pressures are reduced to near zero at the water surface in the drain.

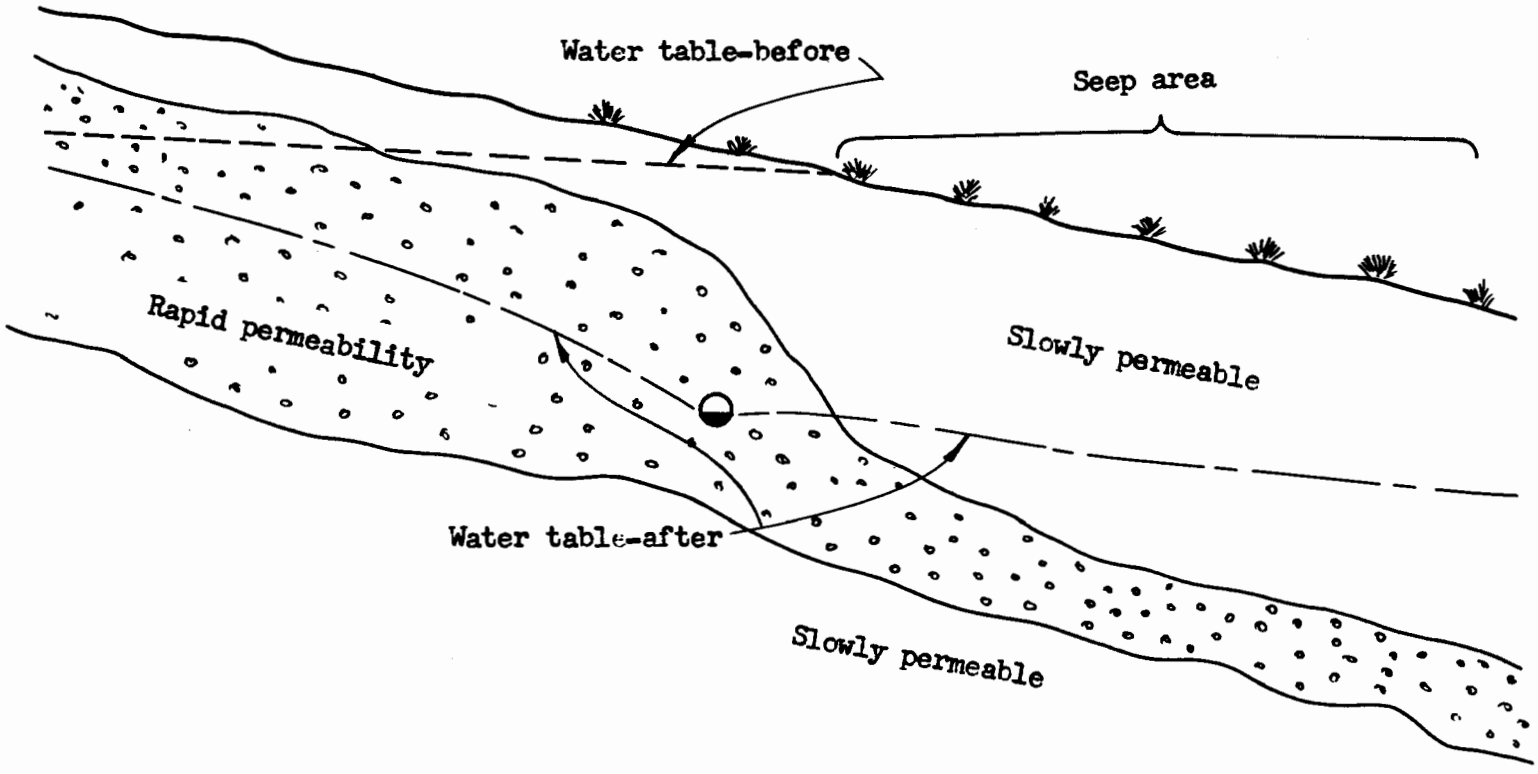
The example cited in Figure 7.18 shows a relief well installation in an interception-type drain. The principles discussed are equally applicable for relief-type drains. In the case of a relief drain under conditions where the water table is nearly flat, the drawdown curves on either side of the drain will be of a similar shape.

Figure 7.19 illustrates another example of a condition where a constricted aquifer forces the water table to the ground surface. The drain shown is a closed-type interception drain located just above the point of constriction. The drain must be located in the permeable material above the point of construction and at a reasonable depth consistent with economic consideration.

Figure 7.20 illustrates a relief-type drain installed in a low area with a very flat water table gradient. This is typical of a great many situations common over a large area. Where the wet area is rather long and narrow, such as a draw or a swale, one relief drain as illustrated in the sketch may solve the drainage problem. Under these conditions the drain should be located in the center of the wet area and it will be effective equidistant on either side of the drain. The new hydraulic gradient established by such a drain must lower the water table to a level below the critical depth throughout the wet area.

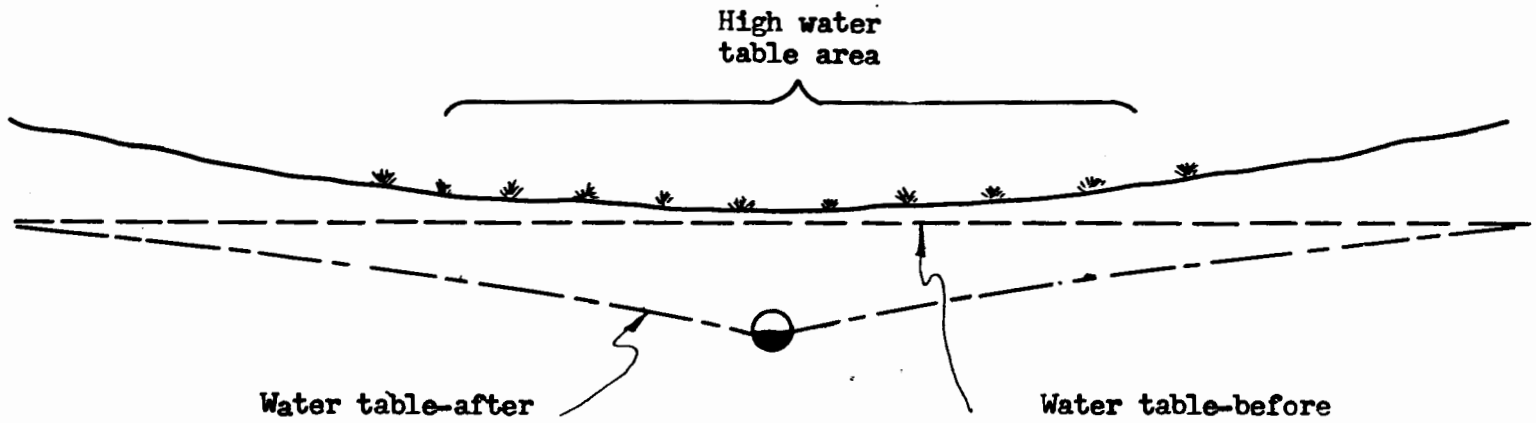
Figure 7.21 illustrates a series or a battery of relief-type drains located in a relatively low area with a very flat water table gradient. This situation is also common over a wide range of field conditions. Each drain in the system is designed to remove the excess ground water from the area it serves and to maintain a minimum water table level between lateral drains. The new water table surface established describes a series of arcs made up by the drawdown curves between drains. This type of system is usually applicable in level areas with slow permeability, where ground water movement is very slow, and where there is little opportunity to intercept ground water flow.

Drains are either open-type or covered-type drains and in the case of subsurface drains they may be either relief or interception-type drains. In the case of open-type drains employed for subsurface drainage under high water table conditions, the required effective depth usually dictates a size and total capacity in excess of that necessary for the quantity of



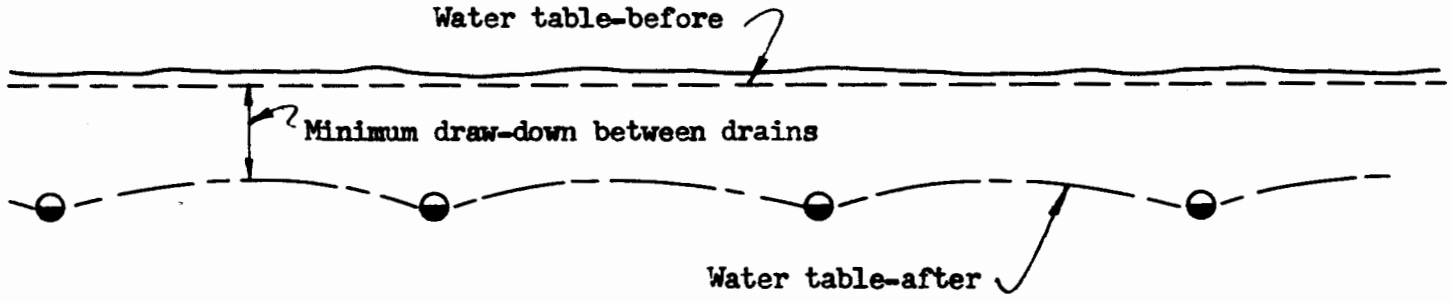
Typical example - Interception drain located at point of constriction of permeable aquifer to lower the water table level and stop surface seep. Open type drain may be used.

Figure 7.19



Typical example - Relief drain placed in center of narrow depression area to lower the water table level through draw-down from either side. May be either open or closed type drain.

Figure 7.20



Typical Example - Relief drains in series to lower a high water table condition on nearly level land with a very flat water table gradient. May be open drains but usually are closed type drains.

Figure 7.21

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Design of Subsurface Drainage (cont'd)

ground water to be disposed of. (Effective depth is defined as the depth of the water table below the land surface.) In the case of covered-type or tile drains employed for subsurface drainage, the required depth is not a factor in the size or capacity of the drain except that it will intercept more ground water by virtue of its greater depth below the water table. This is recognized in the tile spacing formulae and tables that are used.

Subsurface drains, either open or covered-type, serve essentially the same purpose of lowering water table levels. The decision as to which type of drain to use should be based primarily on such factors as cost, availability of right-of-way, maintenance and available slope or gradient. Either type drain will function satisfactorily in lowering water table levels. If cost is not a limiting factor and if land values are relatively high, covered-type drains are always preferable to open-type drains.

Drainage Coefficients. The drainage coefficients used in the design of subsurface drains are generally lower than those used for surface drains. Subsurface drains differ in principle from surface drains in that water percolates into the soil and is then removed by drains located below the ground surface. There is a considerable time-lag in this process as the soil profile serves as a temporary retarding medium or storage reservoir.

In humid areas where average annual rainfall is in excess of 25 inches and where the land has complete surface drainage, either natural or artificial, the following drainage coefficients should be used:

Soil	Drainage Coefficient (Inches to be removed in 24 hours)
*Mineral	3/8 to 1/2
*Organic	1/2 to 3/4

*Mineral soil - Less than 20% organic matter
*Organic soil - More than 20% organic matter

In cases where surface water is admitted to subsurface drains, the surface runoff should be computed from drainage coefficients as described under Surface Drainage, and the drain should be designed to carry both surface and ground water.

In the semi-arid regions where average annual rainfall is less than 24 inches and where irrigation is not practiced, there may be little need for subsurface drainage. Each situation of this kind must be evaluated individually on the basis of local rainfall, frequency and intensity.

In irrigated areas in the semi-arid regions there is considerable need for subsurface drains. The sources of ground water in an irrigated area may be classified into two groups - namely, internal and external sources - with respect to the area under consideration. The internal sources may be

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Drainage Coefficients (cont'd)

(1) deep percolation losses from the irrigation water applied, (2) canal or ditch seepage losses from the canals or ditches within or traversing the project area, and (3) deep percolation losses from precipitation. Deep percolation losses from irrigation are always present in irrigated areas and may vary from 10 to 40 percent of the amount of water applied. Seepage losses from canals and ditches within the area are generally present to some degree except where canals have been lined or processed to prevent seepage. These canal and ditch losses are highly variable depending upon soil and subsoil permeabilities and flow depths, but usually fall in a very general range of about 0 to 50 percent, the average loss being about 25 percent. Deep percolation losses from precipitation vary with local areas depending upon climatic and soil conditions. The external sources of ground water in an irrigated area may be (1) deep artesian ground water, (2) migratory ground water moving into the project area from or through shallow aquifers connected with other irrigated areas extending outside the project area, and (3) seepage or percolation from irrigation canals, streams, lakes or other bodies of water outside the project area. The accretion to ground water from these external sources is usually extremely difficult to determine and requires special investigation. It is impossible to generalize on the accretion to ground water from these sources as each case requires individual site investigation. Considering both the internal and external sources of ground water in an irrigated area, the major sources are usually deep percolation from irrigation and canal or ditch loss. The other sources discussed may be major sources in some cases, but are usually minor sources.

Under normal conditions a portion or all of the ground water is removed from an area by natural processes. When the total quantity of water from these various contributory sources exceeds the total quantity being disposed of through natural processes, the water table will rise and artificial drainage must be employed to lower and maintain the water table level to some point which will not be damaging to crop growth. The problem of determining the quantity of ground water to be removed by artificial means is essentially the same for irrigated and nonirrigated lands except that in the case of irrigated lands provision must be made for the removal of water lost by deep percolation from irrigation losses.

The problem on irrigated land resolves itself into one of determining the losses from the various irrigation sources and adding these to the losses from precipitation. In the arid and semi-arid regions, where irrigation is practiced on a supplemental basis, irrigation systems are designed to deliver full season supplies disregarding any precipitation that may occur during the growing season. If appreciable precipitation does occur during the irrigation period, irrigation applications are reduced accordingly. The total amount of water applied, either through irrigation or by precipitation, is about the same in either case and the loss through percolation will also be about the same. A rational method of approaching this is to make an estimate of the percent loss to deep percolation from

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Drainage Coefficients (cont'd)

irrigation, the percent canal or ditch loss, and the percent loss from other known sources and to apply these percentages to the amount of irrigation water that would be used assuming no precipitation occurred.

Example. Assume the following conditions for a given irrigated area containing 200 acres and in need of subsurface drainage:

(1) From consumptive use studies it has been determined that the deep percolation loss from irrigation is 20 percent.
(2) From ditch flow measurements it has been determined that the field ditch loss is 8 percent of the water applied.
(3) The operator during the peak-use season applies a 4-inch irrigation (gross) each two weeks (14 days) and that no precipitation occurs during this period.
(4) The area under consideration for drainage is isolated from other adjacent areas insofar as ground water inflow is concerned and that there is no accretion from deep artesian flow. This would be a typical situation where relief-type drains would be employed.

20% + 8% = 28% = total loss through percolation

28% x 4" = 1.12 inches lost through percolation each irrigation

$\frac{1.12"}{12"}$ = 0.0933 acre-feet per acre lost through percolation per irrigation

$\frac{0.0933}{14}$ = 0.00666 acre-feet per acre per day lost through percolation

Converting to Flow:

$\frac{0.00666}{1.98}$ = 0.00336 c.f.s. per acre to be removed

200 x 0.00336 = 0.67 c.f.s. ground water returnflow from 200 acres

This is the accretion to ground water from field irrigation losses through deep percolation and should be added to the quantity of surface water to be disposed of. In certain cases, an additional allowance must be made for seepage from the main canal system where it has been established that this is a significant factor. The above example is intended to illustrate a method for determining the amount of water to be removed per acre from general irrigation losses. The results obtained will be as precise as the data available on water application, frequency of irrigation and the estimated deep percolation losses.

2. DESIGN (CONT'D)

Subsurface Drainage (cont'd)

Depth and Spacing of Subsurface Drains. The principles involved in determining the proper depth for subsurface drains are quite different than for surface drains. In the case of surface drains the depth is governed by the required capacity for design discharge allowing for a given or predetermined freeboard. In the case of subsurface drains, the depth is governed by the depth at which the water table must be lowered and very seldom by the total capacity that the drain must have.

As stated earlier, the critical depth of the water table usually varies in the range of 0 to 5 feet depending upon specific local conditions as to soils and the type of crops grown. Under the most ideal conditions relative to subsoil permeability, a subsurface drain can only lower the water table to a depth equal to the depth of the drain. Under normal field conditions the subsurface drain will lower the water table to a depth equal to the depth of the drain in only a relatively narrow area adjacent to the drain. As the distance from the drain increases, the drawdown will be less until at some point its effect is insignificant. This is illustrated by the diagram in Figure 7.21 showing the reduced drawdown effect midway between parallel drains. From this discussion it is obvious that the depth of drains in a parallel or similar system is a function of spacing and depth and the two must be worked out simultaneously.

3. LAYOUT

Staking

Large Drains. In staking large drains of considerable length the staking is generally along a route which was previously established when the design survey was made. Previously established bench marks which were set during the design survey are used for vertical control and the ties, tangent distances and curve information laid out during the design survey establish the route or horizontal control. The center line may be run in directly, or an offset line parallel to the center line may be established. If an offset line is used, it should be so located that it will not be disturbed by construction operation, covered by the spoil, or be inconvenient because of crossing over the spoil banks.

Line stakes should be set at all 100-foot stations and plusses where necessary. Curves should always be staked on the center line of the ditch and not on the offset line. The curves should be staked on a minimum of 50-foot chords.

After the line has been established slope stakes should be set at the intersection of the side slope and the ground surface. The distance to the center line, the cut to ditch grade, and the berm width should be marked on the stakes. The method of setting slope stakes for a dam is described in Part 1 of this handbook. The same procedure is used in setting slope stakes for a ditch except they are marked cut instead of fill. Since the bottom of the ditch has a grade the ditch bottom elevation must be computed for each

3. LAYOUT (CONT'D)

Staking (cont'd)

Large Drains (cont'd)

station or plus and the slope stake cut set accordingly. The staking party should check in on all previously established bench marks to avoid errors as the staking progresses.

Center line stakes and bottom width stakes may be set if the contractor is new and needs them to get started, however, generally these stakes are not necessary for contractors, who have had experience in this type of work.

Cut stakes or grade stakes and line stakes should be set for all culverts and structures that are to be installed. The method of setting stakes for structures is described in Part 1 of this handbook.

Small Farm Drains. Farm drains are generally staked immediately following the preliminary survey to determine feasibility. In this case there is no previously established route or bench mark circuit. Generally an offset line and a bench mark are established and the slope stakes are set using a non-erosive grade which was determined during the feasibility check by the difference in elevation between the area to be drained and the outlet. The slope stakes are marked in the same manner as described for the staking of large drains. Part 1 of the handbook shows an example and the manner of keeping notes in staking a small farm drain.

Subsurface Drains. Open type subsurface drains are staked in the same manner as large drains.

Closed Subsurface Drains. In staking this type of drain the cut stakes are set on a suitable offset line (generally five feet from the center line) and the distance to the center line and the cut is marked on the stake. Batter boards may be used to establish the grade of the tile line. This method of setting batter boards and their use is explained in Part 1 of this handbook.

4. CONSTRUCTION

Subsurface or Open Drains

Surface drains or open ditches involve the movement of earth and the installation of any necessary culverts, bridges, inlet or outlet structures.

Farm drainage ditches may be constructed by ordinary farm equipment if the depth and width is quite small and there is no problem in the disposition of the spoil. Plows, whirlwind terraces or small patrols have been used on ditches up to 18-inches in depth. Slightly deeper ditches may be constructed by road patrols or bulldozers. The larger ditches will require heavy earth moving equipment such as scrapers, elevator graders or draglines. If it is planned to use the excavated earth in filling low

4. CONSTRUCTION (CONT'D)

Subsurface or Open Drains (cont'd)

spots in the field near the ditches, the tractor and carryall is the most satisfactory earth moving equipment. This permits some land smoothing operation that eliminates collection of runoff water in depression areas.

If the area to be drained is wet because of recent rains or a high water table, a dragline may be necessary to excavate the ditch. In some very wet situations the dragline may need to move on "mats".

Scrapers, elevator graders or draglines can remove the earth very closely to the staked dimensions if the operators are capable and know their machines. Very little reshaping to grade should be necessary.

If there is considerable room for the spoil piles the excavated earth should be spread as much as possible to make maintenance much easier and provide a better looking job. All berms should be provided as designed. Openings must be provided in all spoil banks as needed to allow surface water to enter the ditch, or as needed for structures.

The machine operators should check their work occasionally by using a hand level or surveying instrument and by reading elevations or cuts from the slope stakes or grade stakes.

If draglines are used, the boom should be long enough so that the spoil will be cast to its proposed location. Too short a boom or a poor operator may not provide the berm that was determined to be necessary in designing the ditch. Attempting to move a spoil bank at a later date by a scraper or bulldozer is not usually successful.

Culverts and bridges must be installed to the line and grade established in the ditch design. Improper alignment on a culvert may increase maintenance. Culverts at the wrong elevation may change the designed hydraulic grade line, both upstream and downstream from the structure.

Defective or old metal culvert pipe should not be used as their discharge capacity may be reduced or they will have to be replaced at an early date. The fill material around the pipe should be compacted to provide a stable structure and reduce seepage along the pipe. There should be two feet of fill over the culvert before equipment is allowed to travel over the structure.

If pipe drop inlets are installed to bring surface water into the drain ditch, they must be installed as designed. Sloped inlets should be properly constructed to the proper line and grade.

Inspection of the construction work must be made to insure full compliance with plans and specifications, that a workmanlike job is being done, and proper progress is being made.

4. CONSTRUCTION (CONT'D)

Subsurface or Covered Drains

Only high quality tile should be used in covered drains as it is false economy to install poor quality tile. The tile may either be clay or concrete, both of which are very resistant to freezing and thawing and have sufficient strength to support static and impact loads if of good quality. Concrete tile may be affected by acids or alkaline soils and soil tests should be made before installation. Other types of material such as metal, plastic, etc. are being used for drain tile but more information is needed on their adaptability.

The trench for tile should be dug to the specified line and grade starting at the outlet and progressing upstream. The tile trench may be hand dug or a trenching machine used. If the trenching machine does not have a sighting device to maintain grade the last six inches should be hand excavation.

Tile should be laid to true grade and good alignment with the bottom of the trench shaped to the lower third of the tile. This may be done with shovels or a metal shaper the same size as the tile. The tile should be laid so there is approximately 1/8 inch between them, unless the soil is sandy, in which case there should be no crack. If the ends of the tile are not square, they may need to be rotated so the widest opening is at the bottom. Wide cracks on curves may need to be covered with pieces of tile or coal-tar-impregnated paper. If the trench was over excavated and below grade line, backfill with graded gravel to the proper elevation.

Properly made junctions are very important. Any lateral should connect to the main drain at an angle of about 45°, thus directing the water downstream. "T" junctions are sometimes satisfactory but only on very short laterals. Manufactured connections are excellent.

The tile should be checked for grade and alignment prior to backfilling especially on flat grades. There should not be any low places in the tile line.

Backfill over the tile by placing 6 to 12-inches of loose, mellow topsoil shaved from the upper edge of the trench. This must be carefully done so the tile are not moved. In very tight soils corncobs or well graded gravel has been used for blinding, but may not be too effective over a period of years.

The backfilling of the trench may then be completed by using a bulldozer, hoe, grader or blade. All spoil should be heaped over the trench so that the ditch can be crossed after full settlement occurs. Large stones are a hazard during blinding or backfilling operations.

5. MAINTENANCE

Open Drains

The major causes of reduction in ditch capacity and deterioration of the channel are

5. MAINTENANCE (CONT'D)

Open Drains (cont'd)

(1) sedimentation in the channel,
(2) excessive vegetative growth,
(3) bank and channel erosion,
(4) improper land use on the drainage area,
(5) poor location and alignment,
(6) improper depth,
(7) inadequate culvert or bridge capacity, and
(8) failure to provide the necessary legal arrangements to fix responsibility and collect maintenance expenses on group drainage enterprises.

Sedimentation of the channel can be controlled to a large extent by proper land use of the watershed. Prevention of wind and water erosion which deposit sediment in the channel should be accomplished wherever possible by good basic farm plans. Sediment basins are sometimes practical. Ditch and spoil banks should be seeded to grass soon after the ditch has been dug.

The control of excessive tree, brush, grass and weed growth along ditch channels is an important preventative maintenance measure. Studies show that ditch capacities may be reduced by as much as 75 percent due to excessive vegetative growth. The primary methods of control consist of mowing, spraying, grubbing, clearing and burning. Heavy duty mowers can be used for cutting brush. If ditch banks are kept relatively flat such maintenance operations will be easier.

If legal arrangements provide for responsibility and collection of money, a maintenance crew can be organized to carry out a systematic program of maintenance on group drains. Such a crew could be provided with proper mowing and spraying equipment and could have a small dragline to remove silt bars and bank slides.

Farm drains can generally be maintained in good operating condition by the diligent use of normal farm machinery and by utilizing grass where needed to prevent erosion. Ordinary farm mowers when properly used will prevent excessive growth of vegetation in such drains.

Covered Drains

In comparison to open ditches, tile drains require relatively little maintenance. Where open channel outlets are provided, the ditch should be kept free of weed or tree growth and the end of the outlet tube covered with a floodgate, a screen, or a flap gate. Surface water at the outlet end should be diverted away from the tile outlet to prevent silt bars obstructing the tile flow. Where the tile is at a shallow depth, they should be protected from the tramping of livestock and not crossed with machinery during wet periods.

5. MAINTENANCE (CONT'D)

Covered Drains (cont'd)

Roots of trees may grow into tile lines and should be removed if within 100-feet of the tile line. If this cannot be done, tar impregnated compounds in bell-and-spigot pipe may be necessary.

During the first year after installation of the tile line, inspections should be made for evidences of failure. Sinkholes over a tile line may indicate a broken tile or too wide a crack spacing. The necessary repairs should be made as quickly as possible. Surface inlets, if any, should be kept free of weed growth, trash or sediment.

If the tile line is plugged, holes may need to be dug along the tile line at intervals of 50 feet and the material removed by suitable plugs, swabs or a sewer rod. Sometimes sediment can be removed by flushing the tile lines.

CONTENTS

PART 8

IRRIGATION

Subject	Page
1. General	8-1
Definitions and Scope	8-1
State Laws	8-4
Basic Concepts	8-4
Moisture Available for Plant Growth	8-4
Consumptive Use	8-4
Intake Rate	8-6
Irrigation Efficiency	8-7
Relationship to Erosion Control and Drainage	8-7
2. Surveys and Investigations	8-8
Soils	8-8
Topography	8-8
Water Supply	8-9
Quantity	8-9
Quality	8-9
Farm or Ranch Enterprise	8-10
3. Design	8-10
Use of the Irrigation Guide	8-10
Soils	8-10
Crops	8-10
Irrigation Specifications	8-12
Conservation Irrigation Methods	8-12
Level Borders	8-12
Borders	8-14
Furrows	8-15
Cross Slope Furrows	8-18
Contour Furrows	8-18
Corrugations	8-19
Contour Ditch	8-19
Sprinkler	8-19
Sub-Irrigation	8-21
Water Conveyance	8-21
Capacity	8-21
Open Ditches	8-22
Structures	8-24
Land Leveling	8-32
Water Disposal System	8-32

CONTENTS (CONT'D)

PART 8

IRRIGATION

	Subject	Page
4.	Operation	8-34
	Water Management	8-34
	Portable Equipment	8-35
	Check Dams	8-36
	Siphon Tubes	8-36
	Gated Pipe	8-36

LIST OF FIGURES

PART 8

IRRIGATION

Figure Number	Title	Page
8.1	Some Elements Considered in Irrigation Planning	8-2
8.2	Guide for Judging How Much Moisture is Available for Crops	8-5
8.3	Example of Estimate Made to Determine the Amount of Irrigation Water Needed	8-5
8.4	Example of a Page in an Irrigation Guide	8-11
8.5	Maximum Length of Run for Level Borders	8-13
8.6	Maximum Length of Run for Border Irrigation in feet, Alfalfa & Small Grain	8-16
8.7	Maximum Length of Run for Border Irrigation in feet, Sod Forming Grasses	8-17
8.8	Maximum Cross Slope in Furrows	8-18
8.9	Contour Furrows with Terraces	8-20
8.10	Irrigation Ditch Sections with Required Lateral Beds	8-23
8.11	Example of Permanent Ditch Design	8-25
8.12-1	Criteria for Trapezoidal Chute Drop Irrigation Structures (B ≤ 3'-0")	8-27
8.12-2	Criteria for Drive-Through Drop Irrigation Structures	8-28
8.12-3	Criteria for Weir Drop Irrigation Structures (B ≤ 3'-0")	8-29
8.12-4	Criteria for Channel Type Check Irrigation Structures (B ≤ 3'-0")	8-30
8.12-5	Criteria for Channel Type Turnout Irrigation Structures (B ≤ 3'-0")	8-31
8.13	Relief Classes for Surface Irrigated Land	8-33
8.14	Discharge of Siphon Tubes	8-36
8.15	Multiple Outlet Factor for Gated Pipe	8-37

PART 8

IRRIGATION

1. GENERAL

Definitions and Scope

Irrigation is the application of water to the land to eliminate the moisture limitation to crop production. In the broad sense, the practice of irrigation includes the development of the water supply, the conveyance system and the waste water disposal system as well as the methods of applying water to a particular farm or field.

"Irrigation Guides" are part of the Soil Conservation District technical standards. They give design specifications for the recommended irrigation method and information helpful to technicians in advising farmers on proper water application. They have been jointly developed by the Soil Conservation Service, the Agricultural College and other agricultural agencies to provide the best thinking on the adapted crops and methods of irrigation to use under local climatic, soil and slope conditions.

Other portions of this handbook contain information which may be required in planning the water supply and conveyance systems. In particular, the following will be found helpful:

Part 3 - Estimating Rate and Volume of Runoff

Part 9 - Earth Dams and Dugouts

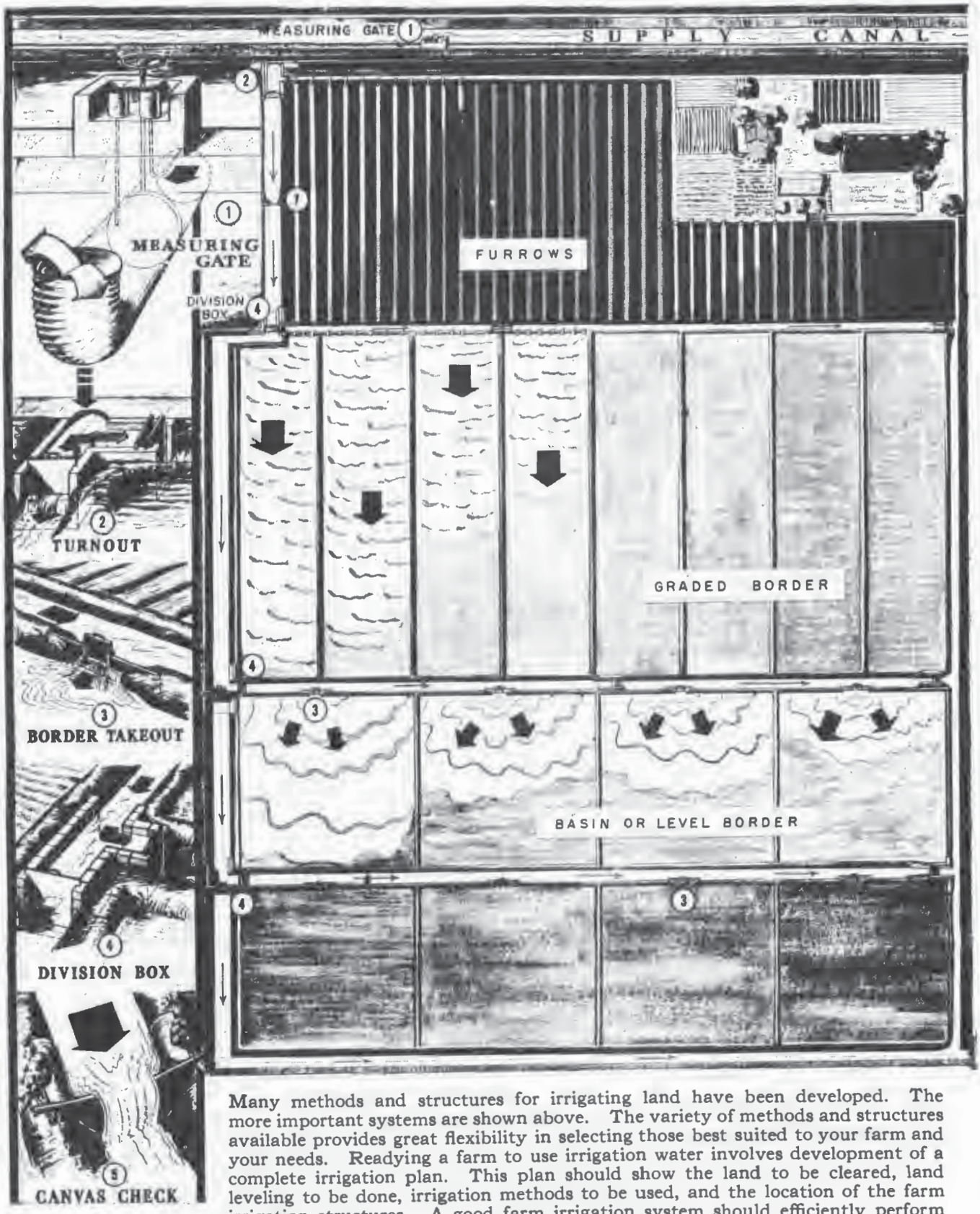
Part 11 - Wells and Pumps

Part 15 - Structures

Part 16 - Hydraulics

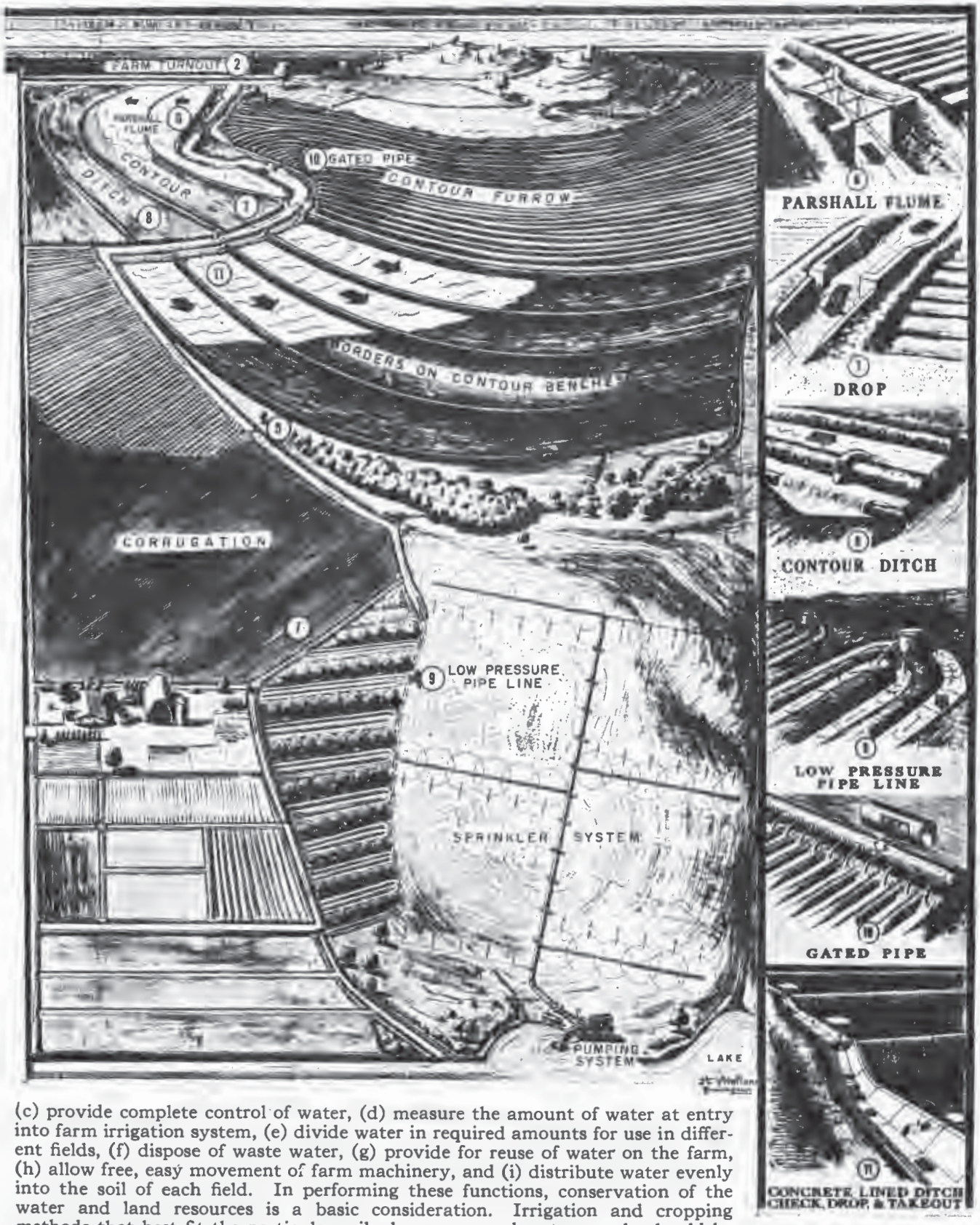
In addition, various chapters in Section 15 of the National Engineering Handbook contain information on particular phases of irrigation design. These have been distributed to work unit offices and cover in detail such subjects as "Irrigation Pumping Plants", "Land Leveling", "Soil-Water Relationships", "Water Measurement", "Border Irrigation", "Furrow Irrigation", "Contour Ditch Irrigation", "Contour Levee Irrigation", "Sprinkler Irrigation", etc.

It is not the intent of this Part of the Engineering Handbook for Work Unit Staffs to attempt to treat completely the broad field of irrigation. Instead, emphasis will be given to planning the irrigated farm, using the Irrigation Guide and assisting the farmer with the more common problems in irrigation facing a Work Unit Staff.



Many methods and structures for irrigating land have been developed. The more important systems are shown above. The variety of methods and structures available provides great flexibility in selecting those best suited to your farm and your needs. Readying a farm to use irrigation water involves development of a complete irrigation plan. This plan should show the land to be cleared, land leveling to be done, irrigation methods to be used, and the location of the farm irrigation structures. A good farm irrigation system should efficiently perform the following functions: (a) deliver water to all parts of the farm when needed, (b) deliver water in amounts needed to meet crop demands during peak use periods,

Figure 8.1 Some Elements Considered



(c) provide complete control of water, (d) measure the amount of water at entry into farm irrigation system, (e) divide water in required amounts for use in different fields, (f) dispose of waste water, (g) provide for reuse of water on the farm, (h) allow free, easy movement of farm machinery, and (i) distribute water evenly into the soil of each field. In performing these functions, conservation of the water and land resources is a basic consideration. Irrigation and cropping methods that best fit the particular soil, slope, crop and water supply should be used. This is conservation irrigation and it makes possible irrigation without: soil erosion damage, saline or alkaline accumulation, water logging, or undue water loss.

in Irrigation Planning

1. GENERAL (CONT'D)

State Laws

Compliance with State Laws in obtaining water rights and in utilizing irrigation water is the responsibility of the cooperator. However, the Service should advise the farmer as to the existence of water laws which might affect his plan or installation. Interpretation of a law or advice on a legal problem is a function of a lawyer. Care must be taken to refer the farmer to qualified attorneys for advice on legal problems.

Basic Concepts

The soil is a storehouse of plant nutrients, a habitat for bacteria, an anchorage for plants and a reservoir to hold water needed for plant growth. The irrigation farmer is interested in maintaining the water supply in the soil for optimum plant growth. To do this, he must know how much the soil profile within the root zone of the plant will hold, how rapidly the plants will use the water and how long it takes to fill the "soil tank" when irrigating.

Moisture Available for Plant Growth. The farmer should be able to estimate how much water is present in the soil at any given time. Figure 8.2 gives a useful guide for estimating the remaining percent of water available to the plant as judged from the appearance of a sample of the soil. In using this method, samples from different depths are taken with a shovel, auger or probe and a calculation made similar to that shown in Figure 8.3 to determine the moisture present and the amount of irrigation water needed. Though this shows the observed data and calculations on a form, after a time or two, the farmer can usually carry the calculations in his head. The field should be examined at several locations when an estimate of this type is made.

Several mechanical devices are commercially available which provide an index of soil moisture. One type measures the change in resistance of an absorbant block buried in the soil. Another measures the tension developed in a closed tube attached to a water filled porous cup in contact with the soil. These instruments have often proven valuable for estimating soil moisture when properly installed on adapted sites.

Consumptive Use. The rate that moisture is used by the plants plus the rate that it evaporates from the field surface is called consumptive use. It is usually expressed in inches per day, inches per month or inches per season. The amount consumptively used in an irrigated field on any given day depends principally upon the temperature, the number of daylight hours, the crop, and the stage of growth of the crop. Such factors as humidity, cloudiness, wind, and surrounding environment are important, but since measurements of this type are not generally available they are usually not considered in estimating consumptive use in Western States.

Soil moisture remaining	Feel or appearance of soil			
	Very light texture	Light texture	Medium texture	Heavy and very heavy texture
0 percent.....	Dry, loose single grained flows through fingers.	Dry, loose, flows through fingers.	Powdery dry, sometimes slightly crusted but easily broken down into powdery condition.	Hard, baked, cracked; sometimes has loose crumbs on surface.
50 percent or less.	Appears to be dry, will not form a ball with pressure.[1]	Appears to be dry, will not form a ball.[1]	Somewhat crumbly but holds together from pressure.	Somewhat pliable, will ball under pressure.[1]
50 to 75 percent.	Same as very light texture with 50 percent or less moisture.	Tends to ball under pressure but seldom holds together.	Forms a ball, somewhat plastic, will sometimes slick slightly with pressure.	Forms a ball, ribbons out between thumb and forefinger.
75 percent to field capacity (100 percent).	Tends to slick together slightly, sometimes forms a very weak ball under pressure.	Forms weak ball, breaks easily, will not slick.	Forms a ball; is very pliable; slicks readily if relatively high in clay.	Easily ribbons out between fingers, has slick feeling.
At field capacity (100 percent).	Upon squeezing no free water appears on soil but wet outline of ball is left on hand.	Same as very light texture.	Same as very light texture.	Same as very light texture.

[1] Ball is formed by squeezing a handful of soil very firmly.

Figure 8.2 Guide for judging how much moisture is available for crops.

1	2	3	4	5	6	7	8	9	10
Depth (feet)	Soil texture					Available moisture capacity	Soil moisture before irrigation		Moisture deficiency
	Very heavy	Heavy	Medium	Light	Very light				
						Inches	*Percent*	*Inches*	*Inches*
0-1			X			2.00	20	0.40	1.60
1-2			X			2.00	40	0.80	1.20
2-3				X		1.25	50	0.62	0.63
3-4				X		1.25	50	0.62	0.63
4-5									
5-6									
Total						6.50		2.44	4.06

Available moisture capacity in inches of water per foot depth of soil under average conditions: very heavy, 2.00; heavy, 2.20; medium, 2.00; light, 1.25; very light, 0.75.

Figure 8.3 Example of estimate made to determine the amount of irrigation water needed.

1. GENERAL (CONT'D)

Basic Concepts (cont'd)

Consumptive Use (cont'd)

The seasonal consumptive use is important in computing the volume of water required to be stored in a reservoir. This rate is expressed in inches or acre inches per acre and is converted to volume by multiplying by the number of acres to be irrigated.

The peak consumptive use is the highest rate that moisture is normally used between any two irrigations during the season. This rate is used to compute the required capacities for irrigation conveyance systems. The ditch or pipe line must be able to deliver water to a field as rapidly as the crop uses it plus the expected deep percolation, runoff and other losses.

Intake Rate. The rate with which water enters the soil is known as intake rate. It includes water that enters through cracks, crevices, holes, etc., which are normally in a field. When water is first applied the rate is high and it gradually decreases as more and more water has entered the soil. Eventually the rate approaches a nearly constant value sometimes called the basic rate.

There are three types of intake characteristics associated with different methods of irrigation. The first is the type where the entire surface of the ground is covered and the water which enters the soil percolates directly downward. This is the intake which occurs when the field is flooded using the border, contour ditch, basin or level border method.

When water is applied with sprinklers, the entire surface is wetted and the moisture moves vertically downward, but because of compaction from the impact of the droplets the intake characteristic is somewhat reduced. This reduction is very slight on soils with extremely high or extremely low intake rates, but is very important in the medium textured range -- especially with soils with a high silt content.

The third type of intake occurs when the surface of the field is only partially covered as with the furrow method of irrigation. In this case the moisture can move laterally as well as vertically. Furrow intake is measured in gallons per minute absorbed in one hundred feet of furrow. Furrow intake rate in gallons per minute per one hundred feet may be approximately converted to inches per hour by dividing the gallons per minute per one hundred feet by the furrow spacing in feet. For example, when corn is in 36" spacing and the furrow intake rate is 1.2 gpm/100 feet, the intake rate over the field is 1.2 ÷ 3 or 0.4 inches per hour.

The importance of intake rate to a farmer is that when surface methods are used it controls the length of time to accomplish an irrigation. If a field will absorb three inches of water in two hours and the desired irrigation is three inches, the irrigator must be prepared to change his

1. GENERAL (CONT'D)

Basic Concepts (cont'd)

Intake Rate (cont'd)

set every two to two and one-half hours or waste water. One of the distinct advantages of the sprinkler method of irrigation is that the application rate may be considerably less than the intake rate of the soil and the irrigation set period may be lengthened to fit in with other farm work.

Irrigation Efficiency. It is impossible to irrigate so that there is not some water wasted. Water may be lost by evaporation or seepage from reservoirs or canal surfaces, by runoff and by unequalities in distribution of water over a field. The consumptive use times one-hundred and divided by the field irrigation efficiency gives the irrigation water requirement at the head of the field. The consumptive use times one-hundred and divided by the farm irrigation efficiency gives the irrigation water requirement at the farm headgate.

Relationship to Erosion Control and Drainage. The planner is faced with the problem of simultaneously meeting the three following requirements:

(1) Requirements for efficient water application without erosion from the applied water.
(2) Requirements for protection against erosion from rainfall.
(3) Requirements for providing required surface and subsurface drainage.

The physical layout requirements for the proper application of irrigation water are often diametrically opposed to the physical requirements for protecting the land from damaging erosion from rainfall. This is especially true with surface methods of irrigation. To protect a field from storm erosion, it is often desirable to align the row direction so the furrows are level, while to best apply irrigation water, it may be most desirable to run the rows directly down the slope. Slope modification through the use of contour irrigation with or without terraces and contour bench leveling are often used to satisfy both requirements. In other instances, conventional erosion control practices are applied and the irrigation water applied by sprinklers.

Similarly the practices of drainage and irrigation are not necessarily congruous. On some soils it could conceivably be desirable to apply irrigation water by ponding methods such as by the use of level borders, but such a practice would not be compatible with the drainage requirement for the removal of excess storm water. On the other hand, land leveling for irrigation in many instances will aid the surface drainage characteristics of a field through the elimination of small ponded areas.

Often the application of irrigation water to land changes the balance between recharge and discharge of the ground water which results in changes

1. GENERAL (CONT'D)

Basic Concepts (cont'd)

Relationship to Erosion Control and Drainage (cont'd)

in the elevation of the water table. Usually when water is diverted onto an area from an outside source, the water table rises and may reach a point where subsurface drainage installations are required. When irrigation water is pumped from the water table, the water table may drop. When subirrigation is the method of applying water, subsurface drainage must necessarily be of a controlled type.

When the planner has met the requirements for efficient irrigation application, effective erosion control and adequate surface and subsurface drainage, he has developed a plan which truly sets a framework for conservation irrigation by the farmer.

2. SURVEYS AND INVESTIGATIONS

Soils

A detailed soil survey is essential to the proper planning of an irrigation system. Such surveys show the soil series and type, or a functional code which describes the characteristics of the soil profile. They provide the basis for use of the irrigation guide in selecting irrigation methods. It is also helpful to obtain specialized information from the soil scientist of any special soil conditions encountered which may affect an irrigation plan.

The field should be examined prior to actual layout with soil characteristics and slope in mind. A change in soil, or significant departure from a uniform slope may cause unequal water application regardless of the size of irrigation stream or length of run.

Topography

Topographic information is essential to the intelligent planning of an irrigation system. As a minimum, surveys should include sufficient detail to show or plan the following:

a. Source and elevation of the water supply to the area under consideration.
b. Landscape features such as fences, buildings, roads, shelterbelts, etc., that may influence the design of the system.
c. Present field boundaries and direction of irrigation.
d. Location and capacities of permanent irrigation ditches and structures.
e. Location and capacities of temporary field ditches or portable pipes and flumes.
f. The drainage pattern of the farm including the location and capacities of waste water disposal ditches and structures.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Topography (cont'd)

The scale and contour interval of topographic maps will vary widely depending upon site conditions and the methods of irrigation under consideration. The scale may vary from 1 inch equals 100 feet to 1 inch equals 400 feet, depending upon the irregularity of the ground surface and the intensity of landscape features. Likewise, the contour interval might vary from 0.5 to 5 or 10 feet depending upon slope. The objective should be to provide a map containing all of the necessary data in sufficient size to show the irrigation plan without undue crowding.

It should be pointed out that topographic maps are not required in all instances for planning irrigation improvements. For example, in the partial reorganization of an existing system, the planning of grade control structures in a properly located ditch might only require a profile and cross section of the ditch with the turnout locations and elevations to field laterals noted. Likewise, the installation of a sprinkler system does not require the same detail of topographic information as is required for a surface irrigation system.

Sub-irrigation systems require special investigations beyond the scope of this handbook. Such problems should be referred to engineering specialists.

Water Supply

Quantity. The quantity of water available for irrigation must be determined. If the source of the water is from a reservoir, the acre feet available during the season should be investigated.

It is also important to know the rate at which the water can be delivered to the farm. This rate is usually expressed in miners inches or cubic feet per second at the headgate or diversion or in gallons per minute, if from a pump.

An investigation should be made to determine the reliability of the water supply and the frequency and season of expected shortages noted.

Quality. When irrigation water is transpired by the plants, most of the salts that were in the water may remain in the soil unless excess water is provided to leach the salts downward. The total concentration of soluble salts, the relative proportion of sodium to other cations, the presence of toxic amounts of boron or other elements, and the relative concentration of bicarbonates to calcium and magnesium should be determined. Facilities are available through State Agricultural Colleges, Public Health Departments, and other laboratories to test water quality. In areas where the water quality is not known, tests should be made and evaluated by soil scientists or specialists.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Farm or Ranch Enterprise

An investigation for planning an irrigated farm is not complete until a knowledge is obtained as to the type of enterprise that the farmer plans to develop. The types of crops to be grown, the labor supply available and the intensity of the operation all have an influence on the layout. In many instances, the farmer or rancher may have preconceived opinions as to the best methods and layout. It is the job of the planner to suggest alternates so as to provide a sound basis for his final decision.

3. DESIGN

Use of the Irrigation Guide

Figure 8.4 shows a typical page in an Irrigation Guide. Since a guide is developed for a specific location, each guide is different and is tailored to meet the conditions of that location. The guide contains principally engineering information that will assist with layout and encourage proper irrigation water application. It should be noted that each soil group is broken into several slope groups, each with separate recommendations.

Soils. Columns 1 and 2 describe the soil profile and give the soil code symbol or series and type for which the irrigation specifications apply. The code symbols are given in the form used locally for soil mapping. In the preparation of the guide, soils having similar intake characteristics and water holding capacities have been grouped.

Column 3 gives the design values for waterholding capacity used. Figure 8.4 indicates that for these soils, the profile will hold 9.6 inches of moisture available to the plant in a depth of 5 feet.

Crops. Column 4 indicates the crops normally considered adapted locally. It does not necessarily mean that other crops may not be recommended. When other crops are to be grown, the problem should be referred to the Area Engineer for specific recommendations.

Column 5 shows the depth from which each crop normally draws most of its moisture. When the soil is shallow, these soil limitation governs.

Column 6 provides information as to the net irrigation which should normally be applied. For example, on these soils the normal net irrigation for potatoes is 2.0 inches while for sugar beets it is 3.9 inches.

Column 7 indicates the fastest rate at which each crop may be expected to use water between irrigations during the summer. Column 8 indicates the number of days the normal irrigation application will last during the peak period. Figure 8.4 shows that potatoes can be expected to use water at a maximum of 0.27 inches a day for a 7-day period while corn will have a peak rate of 0.28 inches per day for a 19-day period.

IRRIGATION GUIDE

FOR

U. S. DEPT. OF AGRICULTURE
SOIL CONSERVATION SERVICE

Sheet ____ of ____
Date ____

SOILS			CROPS					IRRIGATION SPECIFICATIONS							
SITE INDEX	PROFILE DESCRIPTION	AVAILABLE MOISTURE by feet of depth (inches)	LOCALLY ADAPTED CROPS	WATER EXTRACTION DEPTH (feet)	NET MOISTURE TO BE REPLACED EACH IRRIGATION (inches)	PEAK PERIOD CONSUMPTIVE USE RATE (in./day)	IRRIGATION FREQUENCY DURING PERIOD OF MAXIMUM CONSUMPTIVE USE (days)	ADAPTED CONSERVATION IRRIGATION METHODS	INTAKE RATE Border, Flooding or Sprinkler (in./hr.) Furrow or Corrugation (g.p.m./100')	STREAM SIZE Borders or Flooding Unit Stream (c.f.s. Furrows or Corrugations Max. Stream (g.p.m.)	BORDER WIDTH (feet) FURROW OR CORRUGATION SPACING (inches)	MAX. LENGTH OF RUN (feet)	EST. FIELD EFF. (%)	GROSS IRRIGATION APPLICATION (inches)	ESTIMATED TIME REQUIRED (hours)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Very deep (4-8') soils with silt loam surface and silty clay loam to fine sandy loam subsoils and substrata. Soils occur on uplands, terraces and colluvial slopes.	1- 2.0 2- 4.0 3- 6.0 4- 7.8 5- 9.6 6-10.4 7-12.2 8-14.0					SLOPE RANGE 0-0.1%								
			Alfalfa	8	7.0	0.27	26	L. Border	0.5	.003	--	1320	80	9.0	7.0
			Beans	3	3.0	0.24	12	L. Border	0.5	.010	22	1300	65	4.5	1.0
			S. Beets	4	3.9	0.24	16	L. Border	0.5	.0076	22	1320	70	5.5	1.7
			Corn & Sorg	6	5.2	0.28	19	L. Border	0.5	.0052	36	1320	75	7.0	3.1
	Dunlap silt loam		Grass	4	3.9	0.29	13	L. Border	0.5	.0076	--	1320	70	5.5	1.7
	Kadoka silt loam		Potatoes	3	2.0	0.27	7	L. Border	0.5	.014	36	1000	60	3.5	30 min.
	Farland silt loam		S. Grain	4	3.9	0.25	16	L. Border	0.5	.0076	--	1320	70	5.5	1.7
	Keith silt loam						SLOPE RANGE 0-0.25%								
	Goshen silt loam		Alfalfa	8	6.8	0.27	25	Border	0.5	.0020	30--50	1320	75	9.0	10
					7.0	0.27	26	Sprinkler	0.5	--	--	--	75	9.5	--
	Trip silt loam														
			Beans	3	3.0	0.24	12	Furrow	1.4	20	22	850	70	4.5	5.0
	Mitchell silt loam							Sprinkler	0.3	--	--	--	70	4.5	--
	Bridgeport silt loam		S. Beets	4	3.9	0.24	16	Furrow	1.2	20	22	975	70	5.5	8.0
								Sprinkler	0.3	--	--	--	70	5.5	--
	Parshall loam														
			Corn & Sorg	6	5.2	0.28	19	Furrow	1.4	40	36	1600	70	7.5	14
	3331							Sprinkler	0.3	--	--	--	70	7.5	--
	3431														
	32K1		Grass	4	3.9	0.29	13	Border	0.5	.0048	30--50	1320	75	5.0	2.3
	3231							Sprinkler	0.5	--	--	--	75	5.0	--
	M3D		Potatoes	3	2.0	0.27	7	Furrow	2.5	40	36	1025	70	3.0	3.0
	M3D							Sprinkler	0.3	--	--	--	65	3.0	--
	M3K														
	M3T		S. Grain	4	3.9	0.25	16	Border	0.5	.0048	30--50	1320	75	5.0	2.1
	M3T1							Sprinkler	0.5	--	--	--	75	5.0	
	M3U7														
	M4U														

EXAMPLE

							SLOPE RANGE 2-4%								
			Alfalfa	8	7.0	0.27	26	Corrug.	0.4	3	12+	450	55	12.5	45
								Cont.Ditch	0.5	--	--	125	55	12.5	15
								Sprinkler	0.4	--	--	--	70	10.0	--
			Beans C&T	3	3.0	0.24	12	Sprinkler	0.2	--	22	--	70	4.5	--
			S. Beets C&T	4	3.9	0.24	16	Sprinkler	0.2	--	22	--	70	5.5	--
			Corn & Sorg C&T	6	5.2	0.28	19	Cont.Furrow	0.9	20	36	1100	60	8.5	22
								Sprinkler	0.2	--	--	--	70	7.5	--
			Grass	4	3.9	0.29	13	Corrug.	0.5	3	20	350	55	7.0	17
								Cont.Ditch	0.5	--	--	125	55	7.0	7.5
								Sprinkler	0.4	--	--	--	70	5.5	--
			Potatoes C&T	3	2.0	0.27	7	Cont.Furrow	1.6	20	36	700	60	3.5	4.7
								Sprinkler	0.2	--	--	--	65	3.0	--
			S. Grain T	4	3.9	0.25	16	Corrug.	0.5	3	20	350	55	7.0	17
								Cont.Ditch	0.5	--	--	125	55	7.0	7.5
								Sprinkler	0.4	--	--	--	70	5.5	--
							SLOPE RANGE 4-6%								
			Alfalfa T	8	7.0	0.27	26	Cont.Ditch	0.5	--	--	100	50	12.5	15
								Sprinkler	0.4	--	--	--	70	10.0	--
			Beans C&T	3	3.0	0.24	12	Sprinkler	0.2	--	22	--	70	4.5	--
			S. Beets C&T	4	3.9	0.24	16	Sprinkler	0.2	--	--	--	70	5.5	--
			Corn & Sorg C&T	6	5.2	0.28	19	Cont.Furrow	0.9	20	36	1100	60	8.5	22
								Sprinkler	0.2	--	36	--	70	7.5	--
			Grass	4	3.9	0.29	13	Corrug.	0.4	2	20	275	50	8.0	21
								Cont.Ditch	0.5	--	--	100	50	8.0	7.5
								Sprinkler	0.4	--	--	--	70	5.5	--
			Potatoes C&T	3	2.0	0.27	7	Cont.Furrow	1.6	20	36	700	60	3.5	4.7
								Sprinkler	0.2	--	36	--	65	3.0	--
			S. Grain T	4	3.9	0.25	16	Cont.Ditch	0.5	--	--	100	50	8.0	7.5
								Sprinkler	0.4	--	--	--	70	5.5	--

ONLY

Figure 8.4 - Example of a Page in an Irrigation Guide

3. DESIGN (CONT'D)

Use of the Irrigation Guide (cont'd)

Crops (cont'd)

Since irrigation water must be applied to a field as rapidly as the plants use it, these figures provide the basic information for computation of the size of ditch, canal or pipe line needed.

Irrigation Specifications. Columns 9 through 16 provide the information necessary to determine the adapted irrigation method and data for its design. Figure 8.4 shows for example, that with alfalfa on slopes between 0 and 0.1%, level borders are recommended or on slopes up to 0.25%, borders or sprinklers may be used, but on slopes between 2 and 4%, the choice of methods is between corrugations, contour ditch or sprinklers. These columns will be treated in some detail in the next paragraphs.

Conservation Irrigation Methods

Level Borders. The level border method of irrigation consists of surrounding a nearly level area with a low dike and quickly filling the area with the desired amount of water. A temporary pond is created until the water is absorbed by the soil.

Both row crops and close grown crops are adapted to use with level borders as long as the crop is not affected by temporary inundation or is planted on beds so that it will remain above the water level.

The Irrigation Guide in Column 11 gives the Unit Stream Size to use on this particular soil with each crop. A Unit Stream is the size stream which is needed for each strip of land that is one-foot wide and 100 feet long. A level border on these soils when in grass requires a unit stream of 0.0076 c.f.s., and if the border is to be 100 feet wide and 500 feet long, the required stream size is:

$$100 \text{ ft.} \times 500 \text{ ft.} \times 0.0076 \text{ c.f.s./100 sq. ft.} = 3.8 \text{ c.f.s.}$$

The guide also shows in Column 16 that this stream should be turned into the level border for 1.7 hours. A larger stream could be used if the time of irrigation is shortened in proportion, but a smaller stream should not be used for this size level border. If only 2 c.f.s., is available, the border could be made either shorter or narrower or both. If the field layout would conveniently permit the length to be 250 feet, the maximum width can be computed.

$$\text{Width} = 2 \text{ c.f.s.}/0.0076 \text{ c.f.s.} \times 2.5 \text{ hundred feet}$$
$$= 105 \text{ feet}$$

The guide also indicated that the length should not be greater than 1320 feet (Column 13). Figure 8.5 shows the maximum length allowable when border ridges are lower than those anticipated by the guide. A free board

MAXIMUM LENGTH OF RUN
FOR LEVEL BORDERS
in feet
Alfalfa, Small Grain and Grass
n = 0.1486

Unit Stream c.f.s.	d = depth of flow at inlet					
	0.8'	0.7'	0.6'	0.5'	0.4'	0.3'
0.05	450	350	300	225	175	100
0.04	525	425	350	250	200	125
0.03	625	500	400	325	225	150
0.025	700	575	475	350	250	175
0.02	800	675	525	400	300	200
0.015	975	825	650	500	375	250
0.0125	1100	925	725	575	400	275
0.01	1300	1075	850	650	475	325
0.009	1375	1150	925	700	500	350
0.008	1500	1250	1000	750	550	375
0.007	1625	1350	1075	825	600	400
0.006	1825	1500	1200	925	675	450
0.005	2050	1700	1350	1050	750	500
0.004	2400	1975	1575	1225	875	575
0.0035	2600	2150	1725	1325	950	625
0.003	2640	2350	1875	1450	1050	700
0.0025	2640	2640	2150	1650	1200	775
0.002	2640	2640	2475	1900	1375	900
0.0015	2640	2640	2640	2350	1700	1125
0.001	2640	2640	2640	2640	2200	1450

Figure 8.5

3. DESIGN (CONT'D)

Conservation Irrigation Methods (cont'd)

Level Borders (cont'd)

of 0.2' should be provided above the flow depth. Figure 8.4 also shows that with grass the estimated design field efficiency is 70%, (Column 14), and that a gross application of 5½ inches (Column 15), is required to make the normal net application of 3.9 inches (Column 6).

The maximum length of level borders is governed by the maximum height of dike normally considered satisfactory in the area. The length must be shortened if a lower dike is used.

As the intake rate of the soil increases, the stream size must also increase, and so it often becomes impractical to use level borders on sandy soils. However, they can be used if the conditions specified in the guide can be met.

Level borders are very useful when leaching is required to remove salts from the soil profile.

When permanent border dikes are to be used with several crops in a rotation, the largest unit stream listed in Column 11 for the various crops should be used for design.

The area within a level border must be carefully leveled. There should be no cross slope and the total fall within the length of the border should be about half the normal net application depth. Thus, for the 105' x 250' level border in the example above, the total fall in the length of the border should be about 2 inches since the net application for grass is 3.9 inches.

Provision for draining excess water should be provided when the basic intake rate of the soil (Column 10) is less than 1.0 inch per hour or when crops are likely to be damaged by inundation in a period of four hours or less. The drainage gates should remain open except when irrigating.

Borders. With the border method of irrigation, the field is divided into rectangular parallel strips separated by small earth dikes called border ridges. These ridges are broad and low enough so that they can be planted and harvested with the rest of the field.

The border method is adapted to close growing crops. A stream of water is introduced into the upper end and it flows across the field in a sheet between the border dikes. By selecting the proper stream size, a very efficient irrigation application results.

The specifications included in the guide for borders are the same as for level borders. The unit stream is the size stream required for each unit one foot wide and 100 feet long. In addition, a range of border widths usually used in the area is given in Column 12. The selected

3. DESIGN (CONT'D)

Conservation Irrigation Methods (cont'd)

Borders (cont'd)

spacing must not be greater than that which will provide a cross fall within a border of more than 0.1 foot. Thus, on a field which has been leveled to a cross slope of 0.3%, the borders should not be more than 33 feet wide while with a cross slope of 0.2%, 50 foot wide borders may be used. When possible, the cross slope should be zero.

Ideally, borders should have a uniform slope in a downfield direction. When this is not possible, the steepest slope should not be greater than twice the flattest and the slope should either steadily increase or decrease in a downstream direction. Undulating slopes are inefficient.

Figures 8.6 and 8.7 show the maximum length of run as determined by border ridge height and erosive limitations for alfalfa and small grain or grass pasture. Flatter slopes require higher dike heights for the same length of run.

An example might be the use of grass on a slope of 0.2%. Figure 8.4 shows that the unit stream is 0.0048 c.f.s., and that the maximum length of run considered for the area is 1320 feet. Figure 8.7 shows that with this unit stream (use 0.005), the 1320 foot length would require a depth of flow in excess of 0.3', say 0.4'. Normally, 0.2' freeboard is added to this so the settled border ridge height must be 0.6'. If the length could be cut back to 1200 feet or less, the ridge height would be reduced to 0.3' + 0.2' or 0.5'.

Furrows. The furrow method of irrigation is used, as the name implies in the irrigation of crops which are planted in rows with furrows developed between the rows in the planting and cultivating processes.

For the best irrigation efficiency with the furrow method, the largest practical stream should be used to force the water across the field and then the stream should be cut back to the size which will keep runoff losses to a minimum for the balance of the irrigation. The maximum stream size which may be used depends upon the furrow size and shape and the slope. From an erosion standpoint, the maximum stream in g.p.m., should not exceed the value of 10 divided by the slope in percent.

The stream should reach the end of the run within one-fourth of the time that it takes for the desired application to be absorbed. Since the lower end of the furrow also needs to be irrigated, the irrigation should continue for an additional period sufficient to completely irrigate the lower end. Thus the total irrigating time equals one and one-fourth times the period for the desired application to be absorbed, and the time for the water to reach the end of the run equals $\frac{1}{4}/1\frac{1}{4}$ or 1/5 of the total irrigating time.

MAXIMUM LENGTH OF RUN
FOR BORDER IRRIGATION
in feet
Alfalfa and Small Grain
n = 0.1486

Unit Stream c.f.s.	Slope Group												
	0 - 0.25%						0.25 - 0.5%			0.5 - 1%		1-2%	2-4%
	Design Slope												
	0.2%						0.4%			0.75%		1.5%	3%
	Non-Eros.	d = 0.6'	d = 0.5'	d = 0.4'	d = 0.3'	d = 0.2'	Non-Eros.	d = 0.3'	d = 0.2'	Non-Eros.	d = 0.2'	Non-Eros.	Non-Eros.
	Maximum Q per ft. of border width, c.f.s.												
	.2000	.1910	.1410	.0971	.0601	.0306	.1190	.0850	.0433	.0745	.0592	.0443	.0263
0.05	400	375	275	200	125	50	250	175	75	150	125	100	50
0.04	500	475	350	250	150	75	300	200	100	175	150	100	75
0.03	675	625	475	325	200	100	400	275	150	250	200	150	75
0.025	800	775	575	400	250	125	475	350	175	300	225	175	100
0.02	1000	950	700	500	300	150	600	425	225	375	300	225	125
0.015	1325	1275	950	650	400	200	800	550	300	500	400	300	175
0.0125	1600	1525	1125	775	475	250	950	675	350	600	475	350	200
0.010	2000	1900	1400	975	600	300	1200	850	425	750	600	450	250
0.009	2225	2125	1575	1075	675	350	1325	950	475	825	650	500	300
0.008	2500	2375	1750	1225	750	375	1475	1050	550	925	750	550	325
0.007	2640	2640	2025	1375	850	425	1700	1225	625	1075	850	625	
0.006	2640	2640	2350	1625	1000	500	1975	1425	725	1250	975	750	
0.005	2640	2640	2640	1950	1200	600	2375	1700	875	1500	1175	875	
0.004	2640	2640	2640	2425	1500	775	2640	2125	1075	1875	1475		
0.0035	2640	2640	2640	2640	1725	875	2640	2425	1225	2125	1700		
0.003	2640	2640	2640	2640	2000	1025	2640	2640	1450				
0.0025	2640	2640	2640	2640	2400	1225	2640	2640	1750				
0.002	2640	2640	2640	2640	2640	1530	Borders not generally recommended						

Figure 8.6

MAXIMUM LENGTH OF RUN FOR BORDER IRRIGATION in feet Sod Forming Grasses n = 0.1486

Unit Stream c.f.s.	Slope Group												
	0 - 0.25%					0.25 - 0.5%				0.5 - 1%		1-2%	2-4%
	Design Slope												
	0.2%					0.4%				0.75%		1.5%	3%
	d = 0.7'	d = 0.6'	d = 0.5'	d = 0.4'	d = 0.3'	Non-Eros.	d = 0.5'	d = 0.4'	d = 0.3'	Non-Eros.	d = 0.3'	Non-Eros.	Non-Eros.
	Maximum Q per ft. of border width, c.f.s.												
	.2468	.1910	.1410	.0971	.0601	.2380	.1992	.1374	.0850	.1490	.1164	.0886	.0526
0.05	500	375	275	200	125	475	400	275	175	300	225	175	100
0.04	625	475	350	250	150	600	500	350	200	375	300	225	125
0.03	825	625	475	325	200	800	675	450	275	500	375	300	175
0.025	975	775	575	400	250	950	800	550	350	600	475	350	200
0.02	1225	950	700	500	300	1200	1000	675	425	750	575	450	275
0.015	1650	1275	950	650	400	1600	1325	925	575	1000	775	600	350
0.0125	1975	1525	1125	775	475	1900	1600	1100	675	1200	925	700	425
0.010	2475	1900	1400	975	600	2375	2000	1375	850	1500	1175	875	525
0.009	2640	2125	1575	1075	675	2640	2200	1525	950	1650	1300	975	575
0.008	2640	2375	1750	1225	750	2640	2500	1725	1050	1875	1450	1100	650
0.007	2640	2640	2025	1375	850	2640	2640	1950	1225	2125	1675	1275	
0.006	2640	2640	2350	1625	1000	2640	2640	2300	1425	2475	1950	1475	
0.005	2640	2640	2640	1950	1200	2640	2640	2640	1700	2640	2325	1775	
0.004	2640	2640	2640	2425	1500	2640	2640	2640	2125	2640	2640		
0.0035	2640	2640	2640	2640	1725	2640	2640	2640	2640	2640	2640		
0.003	2640	2640	2640	2640	2000	2640	2640	2640	2640				
0.0025	2640	2640	2640	2640	2400	2640	2640	2640	2640				
0.002	2640	2640	2640	2640	2640	Borders not generally recommended							

Figure 8.7

3. DESIGN (CONT'D)

Conservation Irrigation Methods (cont'd)

Furrows (cont'd)

The Guide, Figure 8.4, shows that for corn on a slope between 0 and 0.25%, the maximum stream which may be introduced into a furrow is 40 gallons per minute (Column 11). With this stream, the average furrow intake rate for the normal irrigation, 5.2 inches (Column 6) is 1.4 gallons per minute per 100 feet of furrow (Column 10). With a 36-inch furrow spacing (Column 12), it will take approximately 14 hours to complete the irrigation (Column 16). We would expect the water to have reached the end of the run in 1/5 this time (14 x 1/5 = 2.8 hours). From past experience, it has been found that this stream will advance 1600 feet (Column 13) in 2.8 hours so this is the maximum length of run.

The Guide also shows that the estimated field efficiency is approximately 70% (Column 14) and the gross irrigation application is 7.5 inches.

Cross Slope Furrows. In many fields with smooth slopes, it is desirable to make the rows parallel to a fence or other boundary and the furrows do not run directly down the slope. This introduces cross slope between the furrows which is satisfactory as long as the furrows are deep enough and the soil stable enough so that irrigation water or storm runoff does not break over from one furrow into another. It is good practice to limit the cross slope to one-half the furrow grade.

When the design contemplates cross slope irrigation, the slope group in the Guide should be selected as that which matches the furrow slope (not the land slope).

Contour Furrows. Contour furrows may be used on moderately steep slopes when medium deep furrows can be developed. They may be installed in conjunction with terraces on lands which require terraces for protection against erosion. The allowable cross slope for furrows is shown in Figure 8.8.

Depth of Furrow	Soil Texture		
	Heavy to Med.	Light	Very Light
Deep (9")	8%	5%	2%
Medium (6")	3%	2%	1%
Shallow (3")	0.5%	0.3%	-

Figure 8.8 Maximum Cross Slope in Furrows

Figure 8.4 recommends the use of Contour Furrows (with terraces) on the 2-4% slope range for corn sorghum and potatoes. When used to irrigate potatoes, the Guide recommends the use of a 20 g.p.m., maximum stream size,

3. DESIGN (CONT'D)

Conservation Irrigation Methods (cont'd)

Contour Furrows (cont'd)

with a maximum length of run of 700 feet making a gross application 3.5 inches in approximately 4.7 hours.

The planting of contour furrows must be carefully done. When the guide lines or terraces diverge, the lower guide line should be followed -- when they converge, the rows are made parallel to the upper guide line. This insures that every furrow has a grade at least equal to the grade of the guide lines or terraces. Figure 8.9 shows an example of how this is done.

Corrugations. Corrugations are identical with furrows except they are used with close grown crops and may be spaced in accordance with the properties of the soil instead of the requirements of the crop. In Figure 8.4 it is noted that corrugations are recommended for small grain in the 2-4% slope range. The guide recommends a spacing of 20 inches, the use of a 3 g.p.m., maximum stream and a maximum length of run of 150 feet. The normal gross application of 7 inches would require an irrigation time of approximately 17 hours.

Sometimes corrugations are used in conjunction with other methods to facilitate the spread of water or to reduce crusting damage. They are often used between borders to irrigate a crop up or may be used to guide water to small ridges between contour ditches. When used in this manner, the system design is not based upon the specifications for corrugations but rather upon the specifications for the methods which they facilitate.

Contour Ditch. The contour ditch method is widely used for irrigating close grown crops on steep slopes. With this method, ditches are laid out across the slope on a slight grade. Water is released from the ditches by means of siphon tubes or openings in the ditch bank. Plowing of a furrow on the lower side of the graded contour ditch and throwing the furrow against the lower bank is a simple improvement that allows more uniform distribution of flow and generally increases the efficiency of this method.

The sample Irrigation Guide, Figure 8.4 shows that for small grain on slopes between 4 and 6%, the contour ditch method is adapted, that the average horizontal spacing between ditches should be 100 feet (Column 12) and to apply the normal gross application of 8 inches (Column 15) the set should be run for about 7.5 hours.

Sprinkler. The sprinkler method applies the irrigation water by means of a spray somewhat resembling rainfall. Sprinkler systems are normally designed by the company which sells them, and to do an adequate job, they need to know several things with respect to the site conditions. The Irrigation Guide will give the following required information:

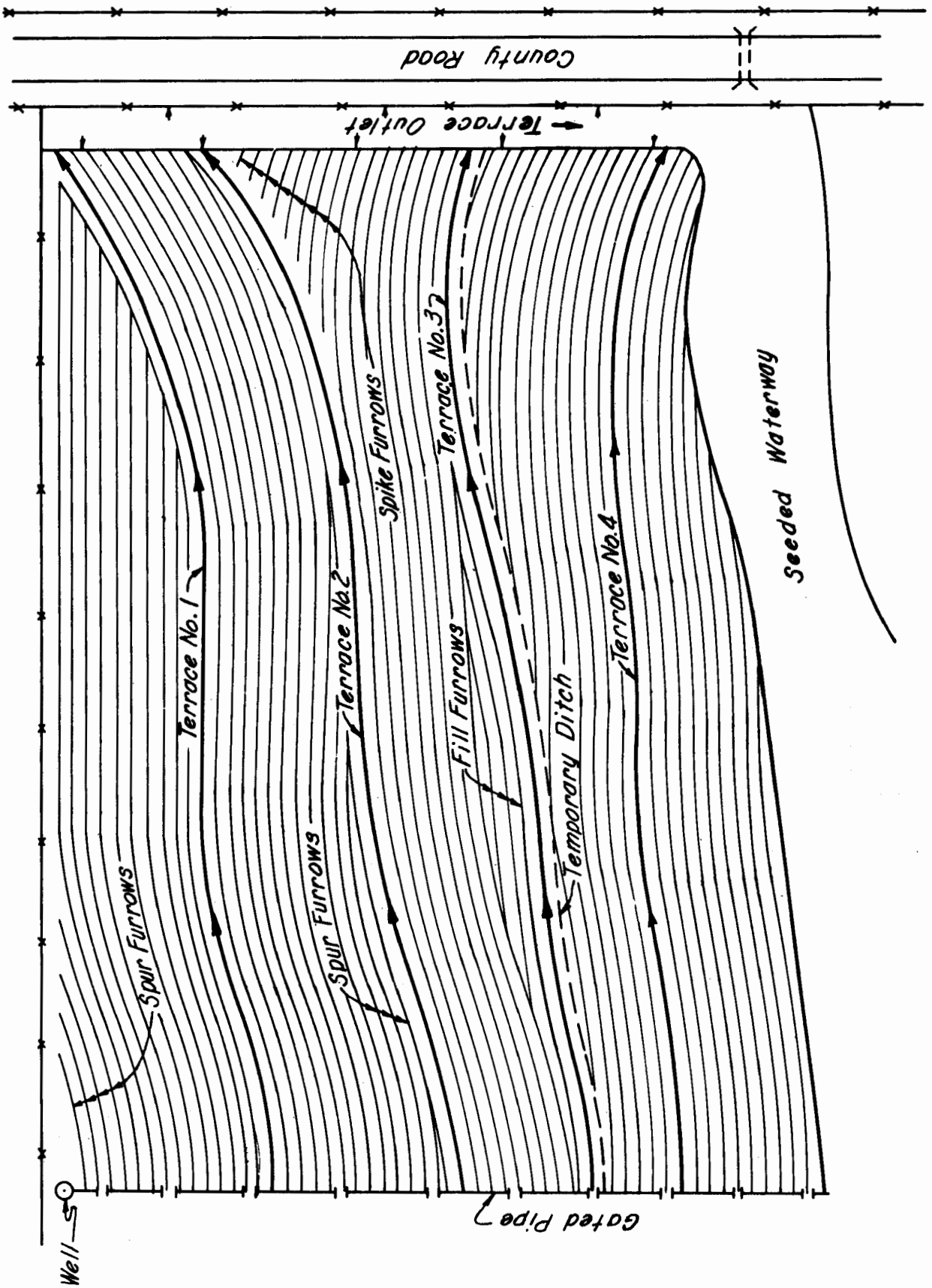


Figure 8.9 Contour Furrows with Terraces

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59M-103

3. DESIGN (CONT'D)

Conservation Irrigation Methods (cont'd)

Sprinkler (cont'd)

1. Is the soil-slope group adapted to sprinklers (Column 9).
2. The peak consumptive use rate (Column 7).
3. Maximum sprinkler intake rate (Column 10).
4. Net moisture to be replaced. (Column 6).

The estimated sprinkler field efficiency is shown in Column 15. The time of application depends upon the rate at which the water is applied and so no figure is shown in the Guide.

Sub-Irrigation. The sub-irrigation method requires rather special site conditions since it is necessary to have complete control of the water table through control of water application and drainage. For this reason, the method is seldom mentioned in the Irrigation Guide. Each site requires special investigations and problems of this nature should be referred to the Engineering Specialists.

Water Conveyance.

Capacity. Irrigation water must be conveyed from its source through a system of canals, pipe lines, structures, etc., to the individual furrow border or sprinkler head. On projects or group systems a canal system usually delivers the required flow to the farm headgate. The farm planner must provide conveyance from the headgate or farm source to the individual field and furrow. The conveyance system must have a capacity to deliver to the field a flow:

1. Adequate to meet the consumptive use of the crops to be grown in the field with proper provision made for the expected field irrigation efficiency, and
2. Adequate to meet the largest irrigation head required for the irrigation methods planned for the field.

For example, let us assume the following site conditions and crops:

Soil: Tripp silt loam.

Slope: 0-0.25%

Crops:		
	Alfalfa	40 acres.
	Corn	60 acres.
	Potatoes	20 acres.
	S. Grain	20 acres.
	Pasture	20 acres.

Irrigation Methods: Largest stream required is 2.0 c.f.s.

3. DESIGN (CONT'D)

Water Conveyance (cont'd)

Capacity (cont'd)

Referring to Figure 8.4, Columns 7 and 14, the calculation is made as follows:

Crop	Acres	Peak Consumptive Use Inch/day	Net Requirement Ac.in./day	Estimated Field Efficiency	Gross Field Requirement Ac.in./day
Alfalfa	40	0.27	10.8	75%	14.4
Corn	60	0.28	16.8	70%	24.0
Grass	20	0.29	5.8	75%	7.7
Potatoes	20	0.27	5.4	70%	7.7
Small Grain	20	0.25	5.0	75%	6.7
	160				60.5

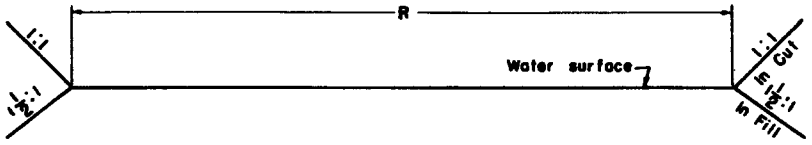
One c.f.s., flow on the field for one hour will provide one acre inch. If the farmer obtains his water from a headgate on a 24-hour basis, he will be receiving 24 acre inches per day for every cubic foot per second he can deliver to the field. Since his peak requirement is 60.5 acre inches, his flow should be not less than 60.5 ÷ 24 or 2.52 c.f.s., to the field. This stream is also of sufficient size to meet the requirements of the irrigation methods to be used.

If he is pumping and only wants to irrigate 12 hours a day, he will need a larger flow. The field flow requirement in this instance would be 60.5 ÷ 12 = 5.04 c.f.s., or 5.04 x 450 = 2268 g.p.m.

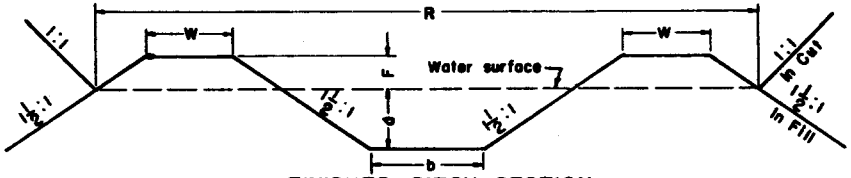
There will be some waste in getting the water from the headgate or pump to the field. If the water is carried in buried or surface pipe lines, this loss may be negligible. In lined ditches, the loss will also be very slight, depending upon the type of lining and its condition. Water conveyed in open unlined ditches may have considerable loss -- sometimes 20%-50% per mile or more on permeable soils. When unlined ditches are used, the farm requirement is greater than the field requirement by the amount of the ditch losses.

Open Ditches. Capacities and dimensions of permanent open ditches are given in Figure 8.10. A ditch must be selected which will safely convey the stream as computed above. For example, when the field requirement was

IRRIGATION DITCH SECTIONS WITH REQUIRED LATERAL BEDS



LATERAL BED BEFORE DITCH IS PULLED



FINISHED DITCH SECTION

								s = 0.0005				s = 0.001				s = 0.002				s = 0.003			
								n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04	
Ditch No.	b	d	F	W	R	A	r	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
	feet	feet	feet	feet	feet	sq.ft.	feet	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs
612	0.5	1.0	0.5	1.00	8.5	2.00	0.49	0.69	1.4	0.51	1.0	0.97	1.9	0.73	1.5	1.37	2.7	1.03	2.1	1.68	3.4	1.26	2.5
1212	1.0	1.0	0.5	1.50	10.0	2.50	0.54	0.73	1.8	0.55	1.4	1.03	2.6	0.78	2.0	1.47	3.7	1.10	2.8	1.79	4.5	1.35	3.4
1812	1.5	1.0	0.5	2.00	11.5	3.00	0.59	0.78	2.3	0.58	1.7	1.10	3.3	0.83	2.5	1.56	4.7	1.17	3.5	1.91	5.7	1.43	4.3
2412	2.0	1.0	0.5	2.50	13.0	3.50	0.62	0.81	2.8	0.60	2.1	1.13	4.0	0.86	3.0	1.61	5.6	1.21	4.2	1.97	6.9	1.48	5.2
1214	1.0	1.2	0.7	1.25	11.3	3.36	0.63	0.81	2.7	0.61	2.0	1.15	3.9	0.87	2.9	1.63	5.5	1.22	4.1	1.99	6.7	1.50	5.0
1814	1.5	1.2	0.7	1.50	12.3	3.96	0.68	0.86	3.4	0.64	2.5	1.21	4.8	0.91	3.6	1.71	6.8	1.28	5.1	2.09	8.3	1.57	6.2
2414	2.0	1.2	0.7	2.00	13.8	4.56	0.72	0.89	4.1	0.67	3.1	1.25	5.7	0.94	4.3	1.78	8.1	1.33	6.1	2.18	9.9	1.63	7.4
1816	1.5	1.33	0.77	1.75	13.6	4.65	0.74	0.90	4.2	0.68	3.2	1.28	6.0	0.96	4.5	1.81	8.4	1.36	6.3	2.22	10.3	1.66	7.7
2416	2.0	1.33	0.77	2.00	14.6	5.31	0.78	0.94	4.9	0.71	3.8	1.33	7.1	0.99	5.3	1.88	10.0	1.41	7.5	2.30	12.3	1.72	9.2
2418	2.0	1.5	1.0	1.50	15.5	6.38	0.86	1.00	6.4	0.75	4.8	1.42	9.1	1.06	6.8	2.00	12.8	1.50	9.6	2.45	15.6	1.83	11.7
3618	3.0	1.5	1.0	2.00	17.5	7.88	0.94	1.06	8.4	0.80	6.3	1.50	11.8	1.12	8.8	2.13	16.8	1.59	12.5	2.60	20.5	1.95	15.4
2421	2.0	1.75	1.1	1.75	17.4	8.10	0.98	1.09	8.8	0.82	6.6	1.55	12.6	1.15	9.3	2.19	17.7	1.64	13.3	2.67	21.6	2.00	16.2
3621	3.0	1.75	1.1	2.50	19.9	9.85	1.06	1.15	11.3	0.86	8.5	1.63	16.1	1.22	12.0	2.30	22.7	1.73	17.0	2.82	27.8	2.11	20.8
4821	4.0	1.75	1.1	3.00	21.9	11.60	1.13	1.20	13.9	0.90	10.4	1.70	19.7	1.27	14.7	2.40	27.8	1.80	20.9	2.94	34.1	2.21	25.6
3624	3.0	2.0	1.3	2.25	21.3	12.00	1.18	1.24	14.9	0.93	11.2	1.75	21.0	1.31	15.7	2.47	29.6	1.86	22.3	3.03	36.4	2.27	27.2
4824	4.0	2.0	1.3	3.00	23.8	14.00	1.25	1.28	17.9	0.96	13.4	1.82	25.5	1.36	19.0	2.57	36.0	1.93	27.0	3.15	44.1	2.36	33.0

A = cross sectional area in square feet.
r = hydraulic radius in feet.
n = coefficient of roughness.
Use n = 0.03 for bare ground.
Use n = 0.04 for grassed ditch bottom.

s = slope in feet per foot.
V = velocity in feet per second.
Q = capacity of ditch in cubic feet per second.

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Figure 8.10 Irrigation Ditch Sections with Required Lateral Beds

5,L-12,917

3. DESIGN (CONT'D)

Water Conveyance (cont'd)

Open Ditches (cont'd)

2.52 c.f.s., and if it is estimated on this soil that the losses in conveying the water to the field is 25%, the ditch capacity should be computed:

$$\frac{2.52}{1.00-0.25} = 3.36 \text{ c.f.s.}$$

If the grade of the ditch is to be 0.001 (0.1%) and the "n" value is 0.03, from Figure 8.9 it can be seen that two ditch sections may be considered. The first is a 2412 ditch (bottom width 24 inches, flow depth 12 inches) which will convey 4.0 c.f.s., with a velocity of 1.13 ft./sec. The second is a 1214 ditch (bottom width 12 inches, flow depth 14 inches) which will convey 3.9 c.f.s., with a velocity of 1.15 feet per second. The first ditch will require a lateral bed width, "R" of 13.0 feet and the second 11.3 feet. This difference may be of importance if there are long lateral fills to build.

In designing a permanent ditch, a profile of the centerline showing the location and elevation of the water supply and any required turnouts, crossings, drainage by-passes, etc., is required. Figure 8.11 shows an example of the design of a permanent ditch. Here the delivery water surface from the Hollis Canal was 86.4. The plan indicates that a turnout was needed at Sta 0+00 and Sta 2+40 and that the water must be delivered to Sta 8+00.

To provide an adequate irrigating head, the water surface should be at least 0.5 feet above the field surface at all delivery points. Control points were then established one-half foot above the ground surface at Sta 0+10, 2+40 and 8+00. The water surface profile was then plotted providing the necessary drop structures and fills so that the elevation of the control points could be met.

Structures. Drops should be placed in a ditch line when the velocity of the water exceeds the allowable velocity as shown in Figure 16.5. Canals lined with bentonite or clay should have velocities not to exceed 1.5 ft./second, or if covered, the permissible velocity for the exposed material. Concrete lined ditches should be held below 10 feet per second.

Drop structures in a ditch line should be placed so that, if desired, they can be used to divert water onto the land. A good rule to use for the location is to place the structure about 10 or 15 feet downstream from the point where the water surface is 0.5 feet above the graded land surface. This procedure appears to place the structures on fill, but since the line represents the water surface and not the ditch bottom, actually the structure will always be on firm ground.

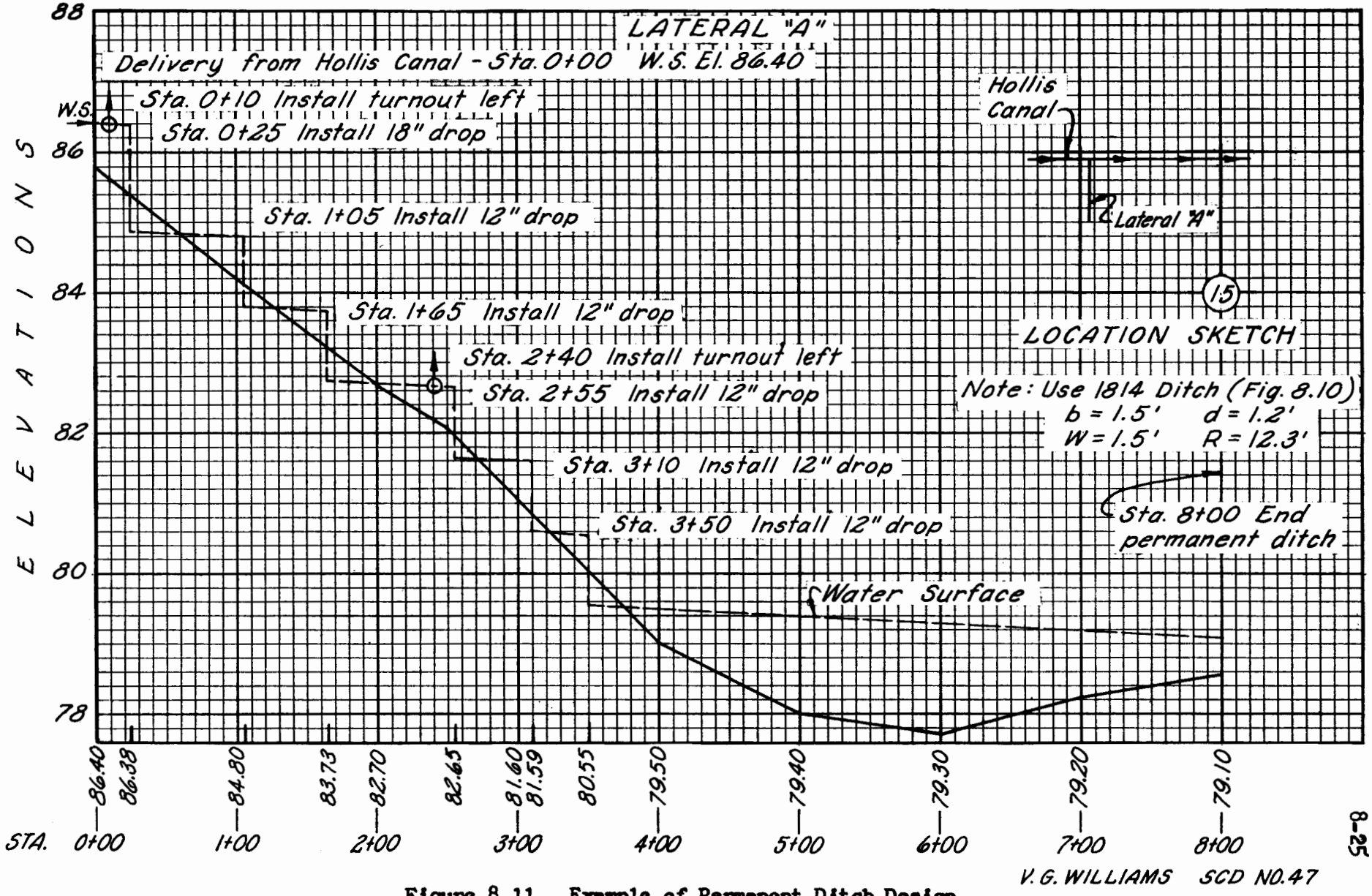


Figure 8.11 Example of Permanent Ditch Design

3. DESIGN (CONT'D)

Water Conveyance (cont'd)

Structures (cont'd)

The height of drop structures selected to lower water from one control point to another must be based on a study of the economics involved and the desires of the farmer. Since two smaller drops take more materials and labor than one larger structure, the tendency in newly irrigated areas is to use fewer, higher drops and keep the cost down. It has been noted that in many of the older irrigated areas, the tendency is to use more small drops to eliminate deep ditches between structures. For small farm ditches, the height of the drop in feet should not exceed the land slope in percent and a drop over three feet in height should seldom be used. With large streams this is sometimes increased. On steep slopes, it is often advisable to utilize a concrete lined ditch section or pipe line to lower the water.

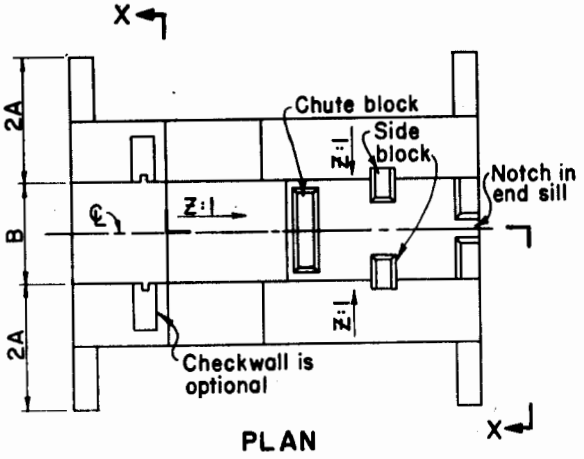
Turnouts should be placed so that it is not necessary to check the water above the design flow of the ditch. This will provide a factor of safety should water be turned down the ditch with the check flashboards still in place.

Crossings should be provided to permit access to the fields for farming and harvesting equipment. Information as to the hydraulic characteristics of culverts can be found in Part 16 of this handbook. With pipe drop structures, a crossing can be provided by extending the length of the barrel and increasing the width of the fill.

In the selection of a specific structure, the depth of flow "d" should always equal the depth of flow in the ditch and the structure capacity should equal or exceed the design flow capacity of the ditch. Standard structures should be used wherever possible and when special design is required, the job should be designed in cooperation with someone having the job approval authority for this work.

Some type of measuring device is needed so the farmer will know how much water he is using and can make the necessary adjustments to provide for efficient use of water. The simplest of all measuring devices is a weir, but these require a considerable drop or loss of head to function accurately. When such head loss cannot be tolerated, a parshall flume may be used. Usually large ditch companies have some sort of measuring device built into the headgate. Some pumping installations are equipped with meters on the discharge line.

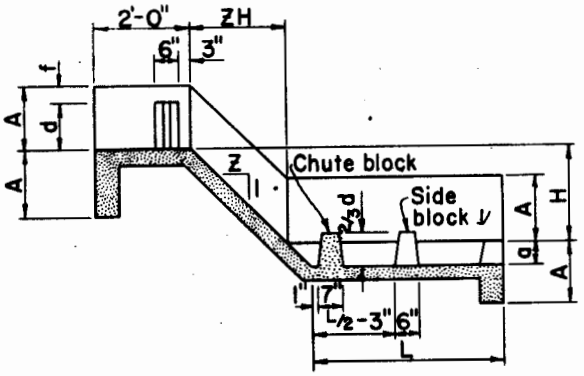
Minimum criteria for certain types of irrigation structures are given in the set of Figures 8.12. This criteria may be used to ascertain if a structure not built according to an SCS standard plan is adequate. In most instances, it is desirable to construct structures exceeding these minimums to provide longer life, better operation or easier construction. Whenever possible, the farmers and contractors should be encouraged to utilize the standard plans already available.



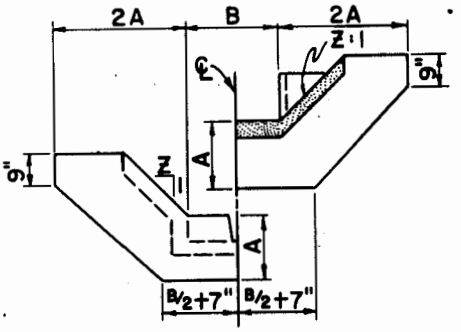
PLAN

NOMENCLATURE:
- B = BOTTOM WIDTH OF STRUCTURE
- d = DESIGN DEPTH OF FLOW
- f = FREEBOARD IN STRUCTURE
- A = d + f
- H = HEIGHT OF FALL OF WATER SURFACE
- a = END SILL HEIGHT
- p = RATIO OF STEEL AREA TO CONCRETE AREA

NOTES:
1. SIDE BLOCKS MAY BE OMITTED WHERE INDICATED IN TABLE.
2. ALL DIMENSIONS SHOWN ARE MINIMUM UNLESS OTHERWISE NOTED.



CROSS SECTION ON ℄



SECTION X-X

MINIMUM DIMENSIONS

d	f	A	a	Z
12"	0'-3"	1'-3"	0'-6"	1
14"	0'-4"	1'-4"	0'-6"	1 1/4
16"	0'-5"	1'-9"	0'-6"	1 1/4
18"	0'-6"	2'-0"	0'-6"	1 1/4

MINIMUM VALUES OF L

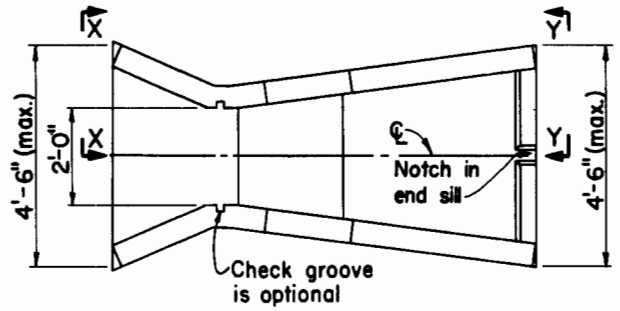
H	WHEN d = 12"	14"	16"	18"
0'-6"	2'-0"			
0'-9"	2'-6"			
1'-0"	2'-6"	3'-6"	4'-0"	4'-3"
1'-6"	3'-0"	3'-9"	4'-3"	4'-3"
2'-0"	4'-0"	4'-3"	4'-3"	4'-3"
2'-6"	4'-9"	5'-0"	5'-6"	5'-6"
3'-0"	5'-6"	5'-9"	6'-3"	6'-3"
3'-6"		6'-6"	7'-0"	7'-0"
4'-0"		7'-3"	7'-9"	7'-9"

CONCRETE MINIMUMS

	WHEN d = 12"	14"	16"	18"
CONCRETE THICKNESS: FORMED WALLS	5"	5"	6"	6"
IN TRENCH	6"	6"	6"	6"
SLAB ON GROUND	4"	4"	4"	4"
REINFORCING REQUIRED WHEN	H ≥ 1'-6"	H ≥ 1'-6"	ALL	ALL
p=	0.0015	0.0020	0.0020	0.0020

CRITERIA FOR TRAPEZOIDAL CHUTE DROP IRRIGATION STRUCTURES (B ≦ 3'-0")

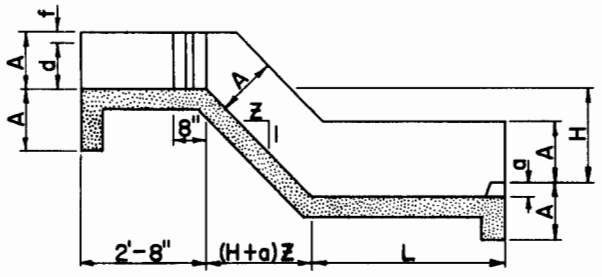
Figure 8.12-1



PLAN

NOMENCLATURE:
- d = DESIGN DEPTH OF FLOW
- f = FREEBOARD IN STRUCTURE
- A = d + f
- H = HEIGHT OF FALL OF WATER SURFACE
- a = END SILL HEIGHT
- p = RATIO OF STEEL AREA TO CONCRETE AREA

NOTES:
1. ALL DIMENSIONS SHOWN ARE MINIMUM UNLESS OTHERWISE NOTED.
2. THE CONCRETE BLOCKS SHALL BE LAID WITH BROKEN VERTICAL JOINTS. THE OPENINGS IN THE BLOCKS SHALL BE ALIGNED VERTICALLY AND FILLED WITH CONCRETE GROUT.



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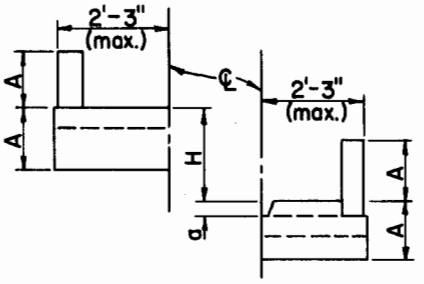


SECTION X-X SECTION Y-Y

CONC. BLOCK MINIMUMS 2/

	WHEN d = 12" TO 14"
WALL THICKNESS	8"
REINFORCING REQUIRED	WIRE MESH IN HORIZONTAL JOINTS AND CORNER BLOCKS DOWELLED

MINIMUM DIMENSIONS

d	f	A	a	z
12"	0'-3"	1'-3"	0'-4"	1
14"	0'-4"	1'-6"	0'-6"	1 1/4

CONCRETE MINIMUMS

	WHEN d = 12"	14"
CONCRETE THICKNESS: FORMED WALLS	5"	5"
IN TRENCH	6"	6"
SLAB OR GROUND	5"	5"
REINFORCING REQUIRED	ALL	ALL
p =	0.0020	0.0020

MINIMUM VALUES OF L

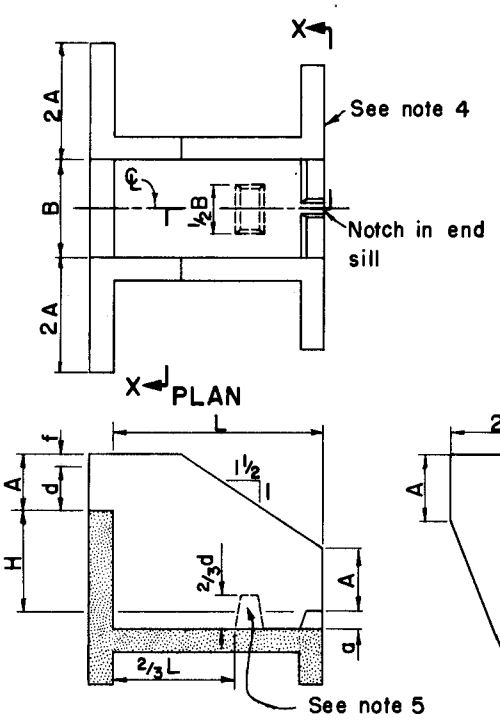
H	WHEN d = 12"	14"
0'-6"	2'-0"	
1'-0"	2'-6"	3'-6"
1'-4"	3'-0"	
1'-6"	3'-0"	3'-9"
1'-8"	3'-3"	
2'-0"	4'-0"	4'-3"

CRITERIA FOR DRIVE-THRU DROP IRRIGATION STRUCTURES

Figure 8.12.-2

NOMENCLATURE:
B = BOTTOM WIDTH OF STRUCTURE
d = DESIGN DEPTH OF FLOW
f = FREEBOARD IN STRUCTURE
A = d + f
H = HEIGHT OF FALL OF WATER SURFACE
a = END SILL HEIGHT
p = RATIO OF STEEL AREA TO CONCRETE AREA

NOTES:
1. ALL DIMENSIONS SHOWN ARE MINIMUM UNLESS OTHERWISE NOTED.
2. THE CONCRETE BLOCKS SHALL BE LAID WITH BROKEN VERTICAL JOINTS. THE OPENINGS IN THE BLOCKS SHALL BE ALIGNED VERTICALLY AND FILLED WITH CONCRETE GROUT.
3. TIMBER SIZES REFER TO NOMINAL DIMENSIONS.
4. IN COHESIVE SOILS LOWER WING MAY BE ELIMINATED FOR STRUCTURES WHERE H ≦ 1'-8"
5. INCLUDE FLOOR BLOCKS WHEN H ≧ 2'-6" WITH EASILY ERODIBLE SOILS



CROSS SECTION ON ℄ SECTION X-X

MINIMUM DIMENSIONS

d	f	A	a
12"	0'-3"	1'-3"	0'-4"
14"	0'-4"	1'-6"	0'-6"
16"	0'-5"	1'-9"	0'-6"
18"	0'-6"	2'-0"	0'-6"

CONCRETE MINIMUMS

	WHEN d = 12"	14"	16"	18"
CONCRETE THICKNESS:				
FORMED WALLS	5"	5"	6"	6"
IN TRENCH	6"	6"	6"	6"
SLAB ON GROUND	4"	4"	4"	4"
REINFORCING REQUIRED WHEN	H ≧ 1'-6"	H ≧ 1'-0"	ALL	ALL
p =	0.0020	0.0020	0.0020	0.0020

MINIMUM VALUES OF L

H	WHEN d = 12"	14"	16"	18"
0'-6"	3'-9"			
1'-0"	4'-0"	4'-9"	5'-6"	6'-3"
1'-4"	4'-2"			
1'-6"	4'-3"	5'-0"	5'-9"	6'-3"
1'-8"	4'-4"			
2'-0"	4'-6"	5'-0"	5'-9"	6'-6"
2'-4"	4'-8"			
2'-6"	4'-9"	5'-3"	6'-0"	6'-6"
2'-8"	4'-10"			
3'-0"	5'-0"	5'-6"	6'-0"	6'-9"

MASONRY MINIMUMS

	AT FLOOR ELEV.	WHEN d = 12"	14"	16"	18"
WALL THICKNESS:					
LOWER WINGWALL	0.3A	6"	6"	6"	6"
UPPER WINGWALL	0.2(H+A)	6"	6"	6"	6"
WEIR WALL	0.5H	6"	6"	8"	8"
SIDE WALL	0.3(H+A)	6"	6"	6"	6"

CONC. BLOCK MINIMUMS 2/

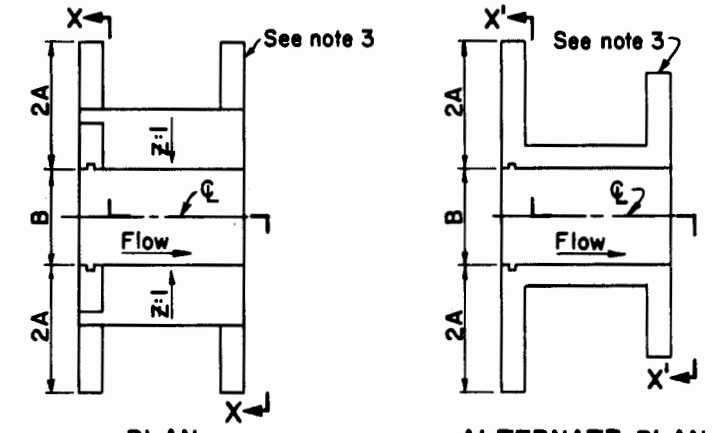
H	BLOCK THICK	REINFORCING REQUIRED
< 1'-0"	8"	NONE
= 1'-0" < 2'-8"	8"	WIRE MESH IN HOR. JOINTS
≧ 2'-8"	8"	WIRE MESH IN HOR. JOINTS AND CORNER BLOCKS DOWELLED

TIMBER MINIMUMS 3/

SHEATHING	2" THICKNESS - TREATED
BATTENS	2" X 4" TREATED - SPACED NOT MORE THAN 3' ON CENTER OR 5' ON CENTER WITH T & G SHEATHING

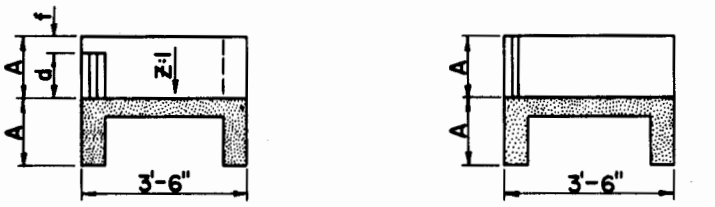
CRITERIA FOR WEIR DROP IRRIGATION STRUCTURES (B ≦ 3'-0")

Figure 8.12-3



NOMENCLATURE:
- B = BOTTOM WIDTH OF STRUCTURE
- d = DESIGN DEPTH OF FLOW
- f = FREEBOARD
- A = d + f
- p = RATIO OF STEEL AREA TO CONCRETE AREA

NOTES:
1. ALL DIMENSIONS SHOWN ARE MINIMUM UNLESS OTHERWISE NOTED.
2. THE CONCRETE BLOCKS SHALL BE LAID WITH BROKEN VERTICAL JOINTS. THE OPENINGS IN THE BLOCKS SHALL BE ALIGNED VERTICALLY AND FILLED WITH CONCRETE GROUT.
3. IN COHESIVE SOILS LOWER WINGS MAY BE ELIMINATED.
4. TIMBER SIZES REFER TO NOMINAL DIMENSIONS.



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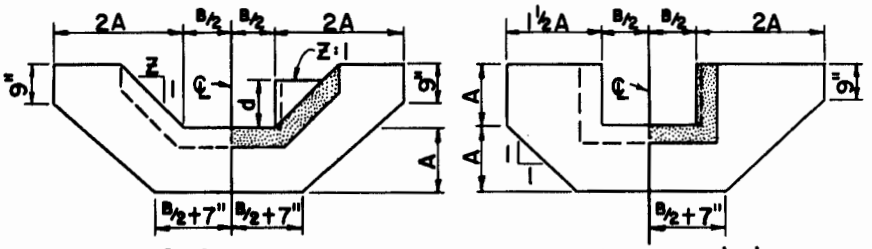


MINIMUM DIMENSIONS

d	f	A	Z
12"	0'-3"	1'-3"	1
14"	0'-4"	1'-6"	1 1/4
16"	0'-5"	1'-9"	1 1/4
18"	0'-6"	2'-0"	1 1/4

CONCRETE MINIMUMS

	WHEN d= 12"	14"	16"	18"
CONCRETE THICKNESS:				
FORMED WALLS	5"	5"	6"	6"
IN TRENCH	6"	6"	6"	6"
SLAB ON GROUND	4"	4"	4"	4"
REINFORCING REQUIRED	NONE	NONE	ALL	ALL
p=			0.0020	0.0020

CONC. BLOCK MINIMUMS 2/

	WHEN d= 12" TO 18"
WALL THICKNESS	8"
REINFORCING REQUIRED	NONE

MASONRY MINIMUMS

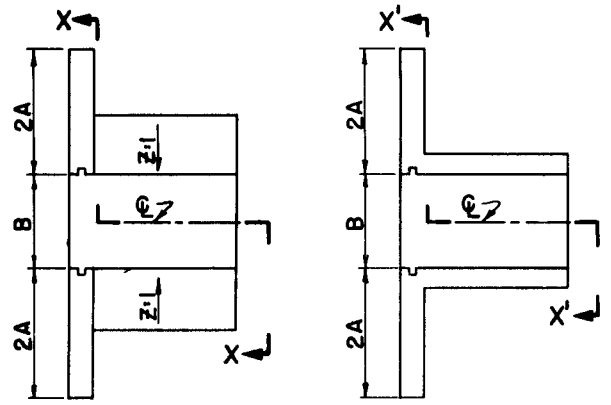
	AT FLOOR ELEV.	WHEN d= 12"	14"	16"	18"
WALL THICKNESS:					
LOWER WINGWALL	0.3A	6"	6"	6"	6"
UPPER WINGWALL	0.2A	6"	6"	6"	6"
SIDEWALL	0.3A	6"	6"	6"	6"

TIMBER MINIMUMS 4/

SHEATHING	2" THICKNESS, TREATED
BATTENS	2" X 4" TREATED-SPACED NOT MORE THAN 3' ON CENTER OR 5' ON CENTER WITH T & G SHEATHING

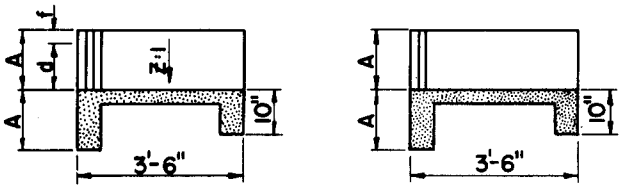
CRITERIA FOR CHANNEL TYPE CHECK IRRIGATION STRUCTURES (B ≦ 3'-0")

Figure 8.12-4



NOMENCLATURE:
- B = BOTTOM WIDTH OF STRUCTURE
- d = DESIGN DEPTH OF FLOW
- f = FREEBOARD IN STRUCTURE
- A = d + f
- p = RATIO OF STEEL AREA TO CONCRETE AREA

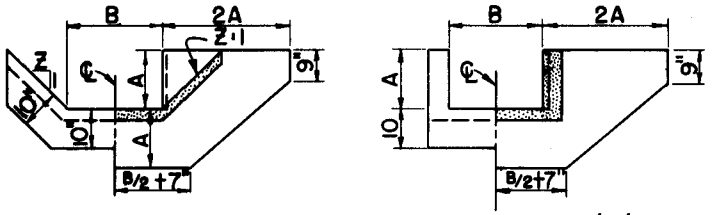
NOTES:
1. ALL DIMENSIONS SHOWN ARE MINIMUM UNLESS OTHERWISE NOTED.
2. THE CONCRETE BLOCKS SHALL BE LAID WITH BROKEN VERTICAL JOINTS. THE OPENINGS IN THE BLOCKS SHALL BE ALIGNED VERTICALLY AND FILLED WITH CONCRETE GROUT.
3. TIMBER SIZES REFER TO NOMINAL DIMENSIONS.



CROSS SECTION ON ℄

MINIMUM DIMENSIONS

d	f	A	Z
12"	0'-3"	1'-3"	1
14"	0'-4"	1'-6"	1 1/4
16"	0'-5"	1'-9"	1 1/4
18"	0'-6"	2'-0"	1 1/4



SECTION X-X SECTION X'-X'

CONCRETE MINIMUMS

	WHEN d = 12"	14"	16"	18"
CONCRETE THICKNESS:				
FORMED WALLS	5"	5"	6"	6"
IN TRENCH	6"	6"	6"	6"
SLAB ON GROUND	4"	4"	4"	4"
REINFORCING REQUIRED	NONE	NONE	ALL	ALL
p =	—	—	0.0020	0.0020

TIMBER MINIMUMS 3/

SHEATHING	2" THICKNESS - TREATED
BATTENS	2" X 4" TREATED - SPACED NOT MORE THAN 3' ON CENTER OR 5' ON CENTER WITH T & G SHEATHING

MASONRY MINIMUMS

	AT FLOOR ELEV.	WHEN d= 12"	14"	16"	18"
WALL THICKNESS:					
WINGWALL	0.2A	6"	6"	6"	6"
SIDEWALL	0.3A	6"	6"	6"	6"

CONC. BLOCK MINIMUMS 2/

	WHEN d = 12" TO 18"
WALL THICKNESS	8"
REINFORCING REQUIRED	NONE

CRITERIA FOR CHANNEL TYPE TURNOUT IRRIGATION STRUCTURES (B ≦ 3'-0")

Figure 8.12-5

3. DESIGN (CONT'D)

Land Leveling

To provide for efficient application of irrigation water by surface methods, it is often necessary to modify the topography of the land to provide more desirable conditions. When such modifications are made according to a plan providing for specific elevations at each point, the practice is called land leveling.

The relief classes for surface irrigated land is shown in Figure 8.13. It should be noted that when the surface relief meets the standards for Class D or E, possible irrigation water efficiencies are poor or very poor and so leveling is required for conservation irrigation. The ideal land surface for surface irrigation is one that has little or no cross slope and a uniform down field slope that is slight enough so that erosion from rainfall and irrigation water is not a problem and yet steep enough to provide adequate surface drainage. The slope limitations must necessarily vary from location to location because of differences in rainfall conditions.

Occasionally fields are found which are ideal in these respects and no leveling is required. Usually however, it is necessary to do some leveling. Over the years, the standards of what is a satisfactory leveling job have gone up and farmers are finding it worthwhile to relevel fields which a few years ago were considered very satisfactory. Many farming areas that are presently leveling land to a "C" class probably will eventually want to go to "B" or even "A" class relief. For this reason, the planner should sell the farmer the best job he will buy at this time. Details of the procedure for designing, staking and leveling land can be found in the SCS National Engineering Handbook, Section 15, Chapter 12, entitled "Land Leveling".

Water Disposal System

A complete water disposal system should be planned for each irrigated farm. This disposal system should be able to safely convey (1) storm runoff, and (2) irrigation waste water to the outlet of the farm without damaging erosion.

On lands that require or have a sub-surface drainage system, this disposal system is incorporated as a part of the drainage design. On lands that require surface water disposal only, the drainage system should, when possible, be built along with and at the same time the lands are leveled.

In many cases, the disposal system will incorporate waterways which are designed principally to carry storm runoff. When irrigation waste is to enter these waterways, special plantings, and maintenance care often must be specified.

Class	Irrigation slope 1/	Cross slope	Possible irrigation water efficiencies	Irrigation operation labor requirement	Method limitations	Leveling requirement
A_1	Uniform but not more than 0.05 percent	None	High	Very low	None	None
A_2	Uniform				Length of level borders is restricted.	
B_1		Uniform but not more than 0.3 percent			Length of level borders restricted. Border widths are restricted.	Leveling desirable to increase length or width of level borders.
B_2		Variable but not more than 0.3 percent		Low		Leveling desirable to reduce labor requirement.
B_3		Either uniform or variable and more than 0.3 percent but not more than 0.5 percent		Moderately low	Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	
C_1	Fairly uniform - (When slopes are over 0.5 percent, convex slopes have maximum grades not over twice minimum; concave slopes have maximum grade not over 1 1/2 times minimum. Undulating slopes not permissible.)	Uniform or variable but not more than 0.3 percent	Good		Level borders not permissible. Border widths are restricted.	Leveling desirable to reduce labor requirement and improve irrigation efficiencies.
C_2		Uniform or variable but not more than 0.5 percent			Border widths are very restricted. Level borders not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils. Corrugations must have down-slope of at least four times cross slope.	
C_3	Either uniform or fairly uniform as defined above	Either uniform or variable and more than 0.5 percent		Moderate to high	Applicable only for contour ditches or to cross slope or contour furrow irrigation within special limitations of furrow depth and soil texture.	
D_1	Variable but without level reaches or reverse grades	Variable but not more than 0.3 percent	Poor	Moderate	Border widths are restricted. Level borders or corrugations not permissible.	Leveling required for conservation irrigation.
D_2		Variable but not more than 0.5 percent		High	Border widths are very restricted. Level borders or corrugations not permissible. Shallow furrows not permissible on coarse or very coarse-textured soils.	
E		Variable and more than 0.5 percent	Very poor	Very high	Applicable only for contour ditches or furrows within special limitations of furrow depth and soil texture.	

1/ Maximum and minimum downfield grades are limited by (1) requirements for drainage, (2) protection from erosion by storm runoff, and (3) the criteria for the irrigation method to be used.

Figure 8.13 Relief Classes for Surface Irrigated Land

4. OPERATION

Proper operation of an irrigation system is equal in importance to the proper design and construction. A perfectly installed system can be fairly efficient if under good management. It is the responsibility of the Soil Conservation Service to give help to the farmer in the proper use of his system.

Water Management

From an application standpoint, irrigation water is considered as being used efficiently when it is spread evenly over a field in the right amount to fill the soil reservoir. However, it is equally important that the principles of maintaining an adequate moisture supply be continued through the entire season. A crop that has suffered a reduced yield because of a lack of water during a part of the growing season has wasted water just as surely as if the irrigations that had been made were individually wasteful.

It has long been recognized that much irrigation water is lost in the conveyance system. In many areas the cost of lining ditches to save irrigation water is economically justified just on the basis of the value of the water alone. In some cases, the damages caused by seepage in canals and ditches makes lining imperative.

Less attention has been given to the deep percolation losses which can occur on the irrigated field itself. Nearly all farmers are conscious of the water that runs off at the end of their fields, but few realize the volume of water which percolates below the reach of the roots and which is just as surely lost to the crop.

Probably the best way for a farmer to evaluate how well he is using his water is for him to keep track of the amount he gets and determine where it goes.

(1) If he has a measuring device, he can easily convert flow measurement to volume. One cubic foot per second of flow (450 g.p.m.) will deliver one acre inch of water in one hour.

(2) If he utilizes the method shown in Figure 8.3, he can easily estimate how much water his soil will hold in inches. Multiplying the inches required by the acres to be irrigated gives the volume needed.

(3) By comparing the volume of water delivered to the volume needed, the farmer can get some idea as to the efficiency of his irrigation. This presupposes that his irrigation water was spread evenly over the field and that the soil reservoir was filled. This can be easily checked by examining the field a day or so after irrigating. If dry layers or spots are still present, the irrigation was not completed or the water was not spread evenly.

4. OPERATION (CONT'D)

Water Management (cont'd)

For example: A farmer has 3 c.f.s., delivered to his field. He has found by examination of his soil that it takes 4 inches of water to fill the root zone. He has been able to irrigate 8 acres per day and an examination of the soil after irrigation shows that the soil reservoir is filled. He can then compute his irrigation efficiency thus:

Water delivered to the farm = 3 c.f.s. x 24 hrs. = 72 ac. in.

Water delivered to the root zone - 8 acres x 4 in. = 32 ac. in.

Irrigation efficiency = $\frac{32}{72}$ x 100 = 44%.

He can also check to see how uniformly the water is being spread over the surface. Perhaps the easiest way is to compare the time the water is on the surface of the ground at the upper end, middle, and lower end of the field. If this period, the "opportunity time", is about the same, it can be assumed that each part of the field is receiving about the same amount of water. If the upper part of the field is receiving too much water, the length of run needs to be decreased or the stream size increased to get the water across the field faster. The latter may not be possible if a larger stream will cause erosion.

With a border, the water should be nearly across the field by the time enough water has been introduced to fill the root zone. With a furrow or corrugation the water should be across the field in one-fifth the total time the water is turned into the furrow or corrugation. After the water gets across, a smaller or "cut-back" stream should be used to complete the irrigation without excessive runoff at the lower end.

One of the most useful tools in improving water management is a knowledge of the approximate time it takes for a given irrigation to be made. While it is true that with surface methods the time will change from irrigation to irrigation, if the farmer knows the normal time, he will be able to compensate for the higher or lower intake rates he may experience. With a sprinkler system, the water is applied at a predetermined rate and it is only necessary to estimate the efficiency of application to compute the time required thus:

$$\text{Time (hrs.)} = \frac{100 \times \text{Net Irrigation Requirement (inches)}}{\text{Efficiency in \%} \times \text{Application Rate (in./hr.)}}$$

Portable Equipment

The farmer has a wide choice of portable irrigation equipment from which to choose. This portable equipment has been developed to provide a more accurate way of distributing water and to reduce the labor requirement in irrigating.

4. OPERATION (CONT'D)

Portable Equipment (cont'd)

Check Dams. Several types of canvas, plastic and metal check dams are available for both lined and unlined ditches. These checks are designed to block the flow of a ditch immediately below the point where the water is to be diverted. They have the advantage that they can be placed at any location and are not in the way when a ditch needs to be cleaned or rebuilt. They are usually adjustable so that the water can be held at some constant level.

Siphon Tubes. Siphon tubes are widely used to withdraw water from an irrigation ditch. They range in size from 3/8 inch diameter to large fabricated siphons which will carry as much as 2 cubic feet per second. The small tubes are usually used for furrows although a number of them may be used together with the border or contour ditch method.

With furrows, the tube sizes are usually selected so that two or three tubes will deliver the maximum stream recommended for the slope under consideration. After the water has crossed the field, one tube is removed to provide the "cut-back" stream. The approximate discharge of small siphon tubes is given in Figure 8.14. The head shown is the difference in height in the supply ditch and the discharge end of the tube or the water level when the discharge end is submerged.

Diameter of Siphon (inches)	Head in Inches					
	2	3	4	5	6	9
	g.p.m.	g p m	g p m	g p m	g p m	g p m
1/2	1.3	1.6	1.8	2	2.1	2.7
3/4	3	4	5	5.5	6	7
1	4	5	7	8	9	11
1-1/3	6	7	8	10	11	13
1-1/4	8	10	12	13	15	18
1-3/8	10	13	15	17	19	23
1-1/2	13	16	18	21	24	28
1-5/8	15	18	22	25	28	33
1-3/4	17	21	25	28	32	38
1-7/8	19	24	29	33	36	44
2	21	27	32	36	40	

Figure 8.14 Discharge of Siphon Tubes

Gated Pipe. Gated pipe is made of light weight metal with small gates spaced to match the furrows. The pipe comes in sections easy for one man to handle and is fitted with simple watertight connections. A slightly different product made of vinyl-coated glass, cloth, butyl, plastic or canvas hose and equipped with small outlets can be used for the same purpose. Gated pipe reduces water losses during conveyance and

4. OPERATION (CONT'D)

Portable Equipment (cont'd)

Gated Pipe (cont'd)

provides a positive control of the water to each individual furrow.

The head loss in a reach of gated pipe with the gates closed is computed the same as for any similar pipe. For the reach in which the gates are open, the friction is first computed as if the entire flow was carried the full length and then multiplied by a factor which depends upon the number of outlets. This factor is given in Figure 8.15.

Some head is required at the last gate to produce flow through the gate. The head necessary depends upon the type of gate used and the desired flow and is usually less than one foot. There may also be an entrance loss of 1.5 velocity head ($H_e + H_v$) as described in Part 16, Hydraulics.

Number of Outlets	Multiple Outlet Factor
5	0.44
10	0.39
15	0.37
20	0.36
30	0.35
50	0.34
100	0.34
∞	0.33

Figure 8.15 Multiple outlet factor for gated pipe

An example of a calculation on gated pipe follows. Let us assume that it is desired to carry 1000 gallons per minute through a gated pipe 1300 feet long and deliver 50 gallons per minute at each gate. The ditch from which the pipe gets the water is 13.5 feet above the far end of the pipe. The gates are spaced 3 to a 10 foot length of pipe.

What size pipe is required if 8" pipe has a friction loss of 2.47 feet per hundred and 10"pipe has a loss of 0.83 feet per hundred.

Given:

Number of Gates (1000 - 50)	20	
Multiple Gate Factor (Fig. 8.20)	0.36	
Length of pipe with gates open	0.67	hundred feet
Length of pipe with gates closed	12.33	hundred feet
Head available	13.5	feet

4. OPERATION (CONT'D)

Portable Equipment (cont'd)

Gated Pipe (cont'd)

Calculations for an 8" pipe

Head required:

Entrance & Velocity Head Loss ($1.5\ V^2/2g$)	1.0 feet
Closed line 12.33 x 2.47	30.5
Open line 0.67 x 2.47 x 0.36	0.6
Pressure at last outlet	1.0
	33.1 feet

Calculations for a 10" pipe

Head required:

Entrance & Velocity Head Loss ($1.5\ V\ /2g$)	0.4 feet
Closed line 12.33 x 0.83	10.2
Open line 0.67 x 0.83 x 0.36	0.2
Pressure at last outlet	1.0
	11.8 feet

A ten-inch gated pipe is required.

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CONTENTS

PART 9

EARTH DAMS AND DUGOUTS

Subject	Page
1. General	9-1
Definition	9-1
Diversion Dam	9-1
Storage Dam	9-1
Grade Stabilization Dam	9-1
Retarding Dam	9-1
Dugout	9-1
Applicable State Laws	9-1
Class of Structures	9-1
Class of Embankment (Density)	9-2
2. Surveys and Investigations	9-3
Site Selection	9-3
Criteria Pertinent to Installations	9-3
Diversion Dam	9-4
Storage Dam	9-5
Grade Stabilization Dam	9-5
Floodwater Retarding Structure	9-7
Dugout or Pit	9-7
Surveys	9-8
Hydrological Investigations	9-8
Soil Mechanics Investigations	9-8
Foundation and Abutment Investigations	9-9
Spillway and Borrow Area Investigations	9-9
Extent of Investigations	9-10
Factors and Characteristics to be Investigated	9-11
Gypsum and/or Soluble Salt	9-11
Dispersion	9-11
Low Volume Weight	9-11
Porous Strata	9-11
Consolidated (Rock) Materials	9-11
Organic Matter	9-12
Investigation of Foundations for Dugouts or Pits	9-12
3. Design of Earth Dams and Dugouts	9-12
Foundations	9-12
Compensatory Measures	9-12
A Core Wall Cutoff	9-13
Foundation Drains	9-13

Subject	Page
3. Design of Earth Dams and Dugouts (cont'd)	9-14
Embankment	9-14
Freeboard	9-14
Design Height	9-14
Embankment Protection from Runoff	9-14
Embankment Protection from Wave Erosion	9-15
Settlement	9-15
Determination of Design Requirements	9-15
Characteristic Analysis of Borrow Materials	9-16
Flood Flow and Annual Yield	9-17
Design Features Related to Storage	9-17
Principal Spillway	9-18
Function	9-18
Alignment	9-18
Diameter of Outlets	9-20
Trash Racks at Entrance of Principal Spillway	9-20
Anti-Vortex Device	9-20
Durability of Materials	9-20
Cantilever Outlets	9-20
Anti-Seep Collars	9-20
Capacities	9-21
Principal Spillway of a Grade Stabilization Dam	9-21
Principal Spillway of a Floodwater Retarding Dam	9-24
Principal Spillway of a Storage Dam	9-24
Principal Spillway for Dugouts	9-24
Emergency Spillways	9-27
Design of Dugouts	9-33
Fencing and Seeding	9-33
4. Layout	9-33
Layout of an Earth Dam	9-33
Structures Designed Before Layout	9-33
Structures Designed at Time of Layout	9-34
Computation of Quantities	9-34
Layout of a Dugout	9-34
5. Construction	9-35
Foundation	9-35
Core Trench	9-35
Foundation Drains	9-35
Embankment	9-36
Borrow Area	9-36
Principal Spillway and Outlet Conduits	9-36
Corrugated Metal Pipe Outlet	9-36
Concrete Box or Pipe Outlet	9-37
Anti-Seep Collars	9-37
Pipe Supports	9-37
Concrete	9-37
Backfill	9-38

Subject	Page
5. Construction (cont'd)	9-38
Livestock Watering Facility	9-38
Excavation of Dugouts	9-38
Fencing	9-38
6. Maintenance	9-39
Maintenance of Embankment	9-39
Maintenance of Emergency Spillway	9-39
7. Equipment	9-39
Engineering Equipment	9-39
Construction Equipment	9-39

LIST OF FIGURES

PART 9

EARTH DAMS AND DUGOUTS

Figure Number	Title	Page
9.1	Typical Section of a Floodwater Retarding Structure-	9-19
9.2	Location of Anti-Seep Collars and Toe Drains - - - -	9-21
9.3	Sectional Elevation of Dam Along Center Line of Principal Spillway and Gated Outlet- - - - - -	9-25
9.4	Typical Stock Water Tank Installation- - - - - - - -	9-26
9.5	Typical Layout and Grading Plans - - - - - - - - - -	9-29
9.6	Typical Condensed Profile Along Center Line of Spillway - - - - - - - - - - - - -	9-30
9.7	Typical Layout and Grading Plans - - - - - - - - - -	9-31
9.8	Typical Condensed Profile Along Center Line of Spillway - - - - - - - - - - - - -	9-32

PART 9

EARTH DAMS AND DUGOUTS

1. GENERAL

Definition

The term earth dam will be used herein to denote an embankment constructed across a water course for any of the following reasons:

a. As a diversion dam to divert a part or all of the water from a waterway or stream into a different water course, an irrigation canal, or a water spreading system.

b. As a storage dam to store surface runoff for irrigation, livestock water, or for fish and wildlife, or to store sediment.

c. As a grade stabilization dam to drop water from one level to another for stabilization of the water course.

d. As a retarding dam to retard floodwater and protect land from inundation or reduce the outflow and permit the use of a more economical system of structures downstream.

A dugout, as the name implies, is simply a hole excavated below the ground surface to provide storage for water. Dugouts are usually located in wide flat drainage channels, at the low point in a pothole, or on fairly flat topography where water can be collected and impounded below the ground surface. Source of supply may be from ground water.

Applicable State Laws

A highly complex body of laws has been built up governing water rights, diversion, storage of water, and construction of dams. Landowners and cooperators should be fully advised of the requirements of state law relating to approval of plans and establishment of the right to store or divert water or construct dams.

Class of Structures

The following broad classes of structures are established to permit the association of criteria with the damage that might result from a sudden major breach of the earth dam embankment.

Class (a) -- Structures located in rural or agricultural areas where failure may damage farm buildings, agricultural land, or township and country roads.

1. GENERAL (CONT'D)

Class of Structures (cont'd)

Class (b) -- Structures located in predominantly rural or agricultural areas where failure may damage isolated homes, main highways or minor railroads or cause interruption of use or service of relatively important public utilities.

Class (c) -- Structures located where failure may cause loss of life, serious damage to homes, industrial and commercial buildings, important public utilities, main highways, or railroads.

The probability of future development of the flood plain area below a structure must be considered in establishing its class.

Structures in series may have a higher damage potential than individual structures and may justify higher factors of safety. Special consideration must be given to such structures.

Structure classes as outlined above are correlated with minimum design criteria. The responsible technician will use the class descriptions as a guide, evaluate each proposed dam site, and make a classification of each proposed structure. The classification will be based on a careful evaluation of potential failure damage and recognition of his responsibility to see that the structure will accomplish the purpose for which it is planned and that its design and construction will be a credit to and enhance the reputation of the Service and himself.

The class of structures primarily considered in this handbook apply to Class (a) structures for which the product of the storage times the height of the dam is less than 3,000 where the storage is defined as the original volume in acre feet in the reservoir at the elevation of the crest of the emergency spillway and the height of the dam is the difference in elevation in feet between the emergency spillway crest and the lowest point in the cross section on the centerline of the dam. Design criteria for larger Class (a) structures and all Class (b) and (c) structures are contained in Washington Engineering Memo #3 Rev.

Class of Embankment (Density)

One of the three classes of embankment may be specified for earth dam construction, depending on site conditions and materials used.

Class I - Class I embankment shall have a maximum dry weight of not less than 95% of that obtained by standard laboratory tests for modified heavy compaction. This requires strict moisture control and compaction equivalent to no less than six passes with a 400 lb/sq. in. sheepsfoot roller over a 6-8 inch lift. A moisture density curve shall be developed for this class of embankment.

1. GENERAL (CONT'D)

Class of Embankment (cont'd)

Class II - Class II embankment shall have a dry weight of not less than 95% of the maximum obtained by standard Proctor tests. This requires rigid to close moisture control (a range of permissible deviation of 5% moisture requirements) and compaction the equivalent of approximately six passes with a 200 lb/sq in. sheepsfoot roller on a 6-8 inch lift. A moisture density curve shall be developed for this class of embankment.

Class III - Class III embankment shall have a dry weight of approximately 85% or more of the maximum obtained by standard Proctor test. The moisture content should be such that, when kneaded in the hand, the soil should just form a ball which does not separate readily (light weight soils may require closer moisture control). The fill material shall be placed in 6-8 inch lifts in the fill or embankment in a manner to provide the maximum travel over each layer. This can be accomplished by starting to spread the loads making up a row or lift at a location so the loaded equipment must travel over the layer to place succeeding loads.

2. SURVEYS AND INVESTIGATIONS

Site Selection

In choosing the site for any structure the utmost care must be taken to be certain it meets the purpose.

Criteria which must be found in the site of all installations are as follows:

(1) The topography must provide adequate abutments to anchor the ends of the dam.

(2) Emergency spillways shall be planned for all installations.

(3) The material and condition of the foundation must be adequate to support the embankment, the principal spillway and emergency spillways in a satisfactory manner.

(4) The foundation should have good drainage or it should be possible to provide it to insure stability of the installation.

(5) If permanent or temporary storage of water is a feature of design, storage space must be available.

(6) For sediment storage or flood water retarding dams and for ponds, a capacity for silt storage must be available.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Site Selection (cont'd)

(7) The watershed or drainage area must be analyzed for both runoff and sediment production. Runoff must be adequate if a water supply for stockwater, wildlife, or irrigation is desired. The sedimentation rate must be within acceptable limits for any installation.

(8) If permanent storage of water is desired, the seepage rate into the impoundment area through the foundation and abutments, as well as through the embankment, must be low. Excessive seepage losses must be correctable.

(9) Borrow material of good quality and in sufficient quantities must be available for the embankment. It must also be within economic hauling distance from the structure.

(10) Water for moisture in the embankment must exist in the natural borrow materials or be provided from outside sources.

(11) The site must be free of debris, obstruction, or trees, or they must be removable for a reasonable cost.

(12) The site must be sufficiently dry and accessible for construction equipment to operate or it must be possible to provide these conditions for a reasonable cost.

(13) The site must be considered for its inter-relation with existing or future structures.

(14) The possibility of a proposed dam impounding water on adjacent property must be investigated. If the dam causes inundation of lands under another ownership, or in any other manner affects another ownership or public property, an easement to allow this encroachment is necessary before the construction begins. If an easement cannot be obtained, the site should be abandoned.

Diversion Dam. A diversion dam to divert water from a stream or water course must be located in a position from which the water may be conveyed. As a rule this will mean constructing where the banks of the channel and the adjacent land are not more than a few feet above the bed of the stream. If the dam is to be placed on a large stream where flood flows may be damaging, the embankment portion of the structure may be protected against erosion by topographic features such as a broad spillway area, a bend in the stream, or a large promontory. When a diversion dam is used across a waterway to pick up the runoff and convey it into a diversion, the location of the dam may be most dependent upon the location of the diversion and its outlet.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Site Selection (cont'd)

Storage Dam. A storage dam site must provide capacity and conditions for storage of water and/or sediments as the case may be.

(1) The area for deposition above a sediment storage dam must be of less value than the area where the uncontrolled sediments have been accumulating, or the deposition must improve the site for later use (heavier sediments over sand or gravel or lighter sediments of heavy bottom lands) or the plan is not economically sound.

(2) A stockwater dam must be accessible without undue travel distances.

(3) The land use above a dam for storage should be of a nature that silting of the reservoir will not be a serious problem. Dams should not be located below an appreciable area of cultivated land unless land treatment is complete.

(4) A water course with a low gradient that is narrow and deep at the dam site, widening upstream to form a sizable basin provides a maximum storage with a minimum fill.

(5) The drainage area for a water storage dam should be large enough to assure a dependable water supply. Drainage areas appreciably larger than necessary should be avoided since the larger flows increase the cost and hazards of structures. Procedures for estimating surface yields may be found in Part 3. A rough estimate of the storage capacity of the reservoir is obtained from the formula: Surface area (in acres) times 1/3 depth (in feet) equals the capacity in acre feet. Where accurate measurements are necessary a contour map of the reservoir should be made.

Grade Stabilization Dam. A grade stabilization dam is used to control a gully head or overfall and provide for the drop of the water from a higher to lower grade, for stabilization or restoration to a higher elevation of a channel floor and also to drop water from a waterway, terrace, or diversion to an adjacent water course at some lower elevation to avoid erosion and formation of a gully. Where a grade stabilization dam is constructed to stabilize an overfall, it must be carefully located to accomplish the job. One way to insure this is to construct the drop on the site of the overfall. The inlet should be set at the desired elevation for the inflowing channel, making sure that the slope of the new channel will be the most desirable. The slope upstream should be flat enough to insure stability (see SCS-TP-61) yet not flatter than is necessary. To build an excessively flat grade requires more material and labor and also tends to establish a bigger waste area in the pool.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Site Selection (cont'd)

Grade Stabilization Dam (cont'd)

Because of past deposition in the waterway above the site, it is frequently possible to re-shape the channel by removal of the deposited sediments, and thereby reduce the amount of grade control needed. The drop established at the outlet of a terrace, diversion, or waterway, etc., will follow the same principles.

Where a grade stabilization dam is constructed downstream any appreciable distance below the overfall, either one of two additional features must be present to control the overfall.

(1) If the void of the gully (depth, width, and length) between the overfall and the drop inlet is not great and the slope, cross section, and fertility of the completed channel are within necessary limits, the gully banks may be bulldozed in and a stable waterway developed between the overfall and the structure.

(2) If the void is not greater than the anticipated production of runoff and sediment from the watershed, the water and silt will maintain a support of the overfall until natural accumulation has created a stable channel between the overfall and the structure. Installations which are made too far below the overfall both vertically and horizontally will not arrest the advance of the gully head.

When a grade stabilization dam is used to stabilize or restore elevation of a channel floor, its location may be less critical than above. Usually the longest reach will be benefited for the landowner if the structure is placed just before the channel leaves the property. If combined with structures upstream, especially from field level into the gully, many of the same principles will apply as for an overfall solution. The new upstream grade to be established will be important. The hydraulics of the reach should be analyzed by waterway standards (SCS-TP-61). This analysis will indicate the need, if any, for channel shaping. In some cases, natural deposition and vegetation may be depended upon for eventual stabilization without channel shaping. Where high vertical gully banks exist and sloughing is anticipated, this accumulation should also be planned for. Except for sloughing, the grade built up in a channel by sedimentation will not be as steep (for a long time) as a degrading slope, nor as steep as the slope it is possible to construct and stabilize in a vegetated waterway. In some cases, in deeply gullied areas, it is more acceptable to stairstep structures than to incorporate all of the grade control in one installation. In other words, two installations with 20 feet of drop in each may be more desirable than one installation with 40 feet of drop.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Site Selection (cont'd)

Floodwater Retarding Structure. The floodwater retarding structure frequently has the dual purpose of grade control and detention of runoff. The location needs for grade control will be as discussed under drop inlets. Site selection for a detention dam must consider the following features:

(1) Does the site provide sufficient storage for sediments and runoff to meet the needs of the plan?

(2) Do the topographic features provide the most economic structure obtainable?

(3) Does the topography provide opportunity for a good emergency spillway?

(4) What is the value of the inundated area in relation to benefits and in relation to alternate sites?

(5) Does the site interfere with any existing structure or feature which is fixed?

(6) Is the quality of land treatment in the watershed high enough to produce a low rate of sedimentation?

(7) Are foundations and abutments adequate to support the structure?

(8) Is borrow material available in the quality and quantity needed?

(9) Are the benefits to be accrued sufficient to warrant the expenditure?

Dugout or Pit. In locating the site for a dugout or pit, the following points should be considered:

(1) The watershed must be capable of furnishing runoff sufficient to maintain a water supply in the dugout; diversion ditches can sometimes be used to supplement the drainage area. The area should be well vegetated, or treated to reduce sedimentation.

(2) At locations where the water table rises within a few feet of the ground surfaces, dugouts can be constructed to intercept this water, adjusting the depth to the fluctuation expected. Locations of this type require little, if any, contributing drainage area to assure a stable water supply. It may be necessary over a period of years to remove the silt or impervious layer from the bottom and sides to allow the water to seep and collect in the dugout.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Site Selection (cont'd)

Dugout or Pit (cont'd)

(3) The subsurface material at the site must be thoroughly investigated to determine the permeability. Since the capacity of a dugout is small, seepage and evaporation losses will have a major effect on the permanency of the water supply. Generally, the seepage rate will be reduced with age by the sealing with silt. Dugouts should not be constructed when porous soils are present in the site unless they are intercepting ground water or are to be sealed.

Surveys

The procedure for surveys for embankments, profiles, cross sections, topography, slope stakes and structural stakes will be found in Part 1 of this Handbook.

Adequate surveys should be made to show location, topography of reservoir when applicable for storage, cross section of gully, and profile of gully and spillway for simple structures. For larger structures, particularly those which are to be planned or reviewed by others, topography should be shown for the dam site and spillway area. Care must be taken to assure proper and complete presentation of all survey data.

Hydrological Investigations

The procedure for analysis of the watershed and its hydrological characteristics will be found in Part 3 of this Handbook.

For dugouts or pits which intercept the water table, the depth to water and its seasonal fluctuations should be determined.

Soil Mechanics Investigations

There is no set rule on the amount of soil investigations required by different size structures. Obviously, foundation or embankment condition can be more critical for a large structure than for a small one. If the site is in an area of soils high in soluble salts or gypsum, conditions may be critical regardless of the size of the structure. Investigation of borrow areas for a large structure will be more extensive than for a small structure because of the need for greater yardage. Despite the fact that a large structure will usually require a greater amount of investigation, the importance of thorough investigation and sampling of sites regardless of size cannot be over-emphasized.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Soil Mechanics Investigations (cont'd)

Foundation and Abutment Investigations. Foundation and abutment investigations are made to determine their adequacy.

(1) To insure stable support for the structure under all conditions of loading:

a. All strata must have sufficient bearing power to prevent crushing, excessive consolidation, displacement, or plastic flow.

b. Sufficient frictional resistance must exist between all strata or between the foundation and the dam to prevent sliding.

c. The foundation and/or abutments must be relatively insoluble and resistant to erosion to prevent the eroding or washing away of the material from upstream, downstream, or under the dam.

(2) To insure that the movement of water through the foundation and/or abutment will not cause:

a. Piping and scour under the dam.

b. Excessive loss of water stored behind the dam.

c. The formation of excessive uplift pressure.

(3) To indicate the possibility of site relocation when:

a. Examination reveals that foundation conditions are entirely unsuitable for the type of structure desired.

b. Foundation conditions are such that a safe design will exceed permissible economic limits.

Spillway and Borrow Area Investigations. Investigations are made to determine suitability of the materials for use in the embankment, presence of materials that will cause difficulty in excavation and the erodability of the material when subjected to spillway flow.

(1) Permeability - Permeability of compacted material should be low.

a. To prevent piping.

b. To prevent excessive loss of stored water.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Soil Mechanics Investigations (cont'd)

Spillway and Borrow Area Investigations (cont'd)

(2) Compacted weight - Relatively high compacted weight is needed to provide resistance against sliding.

(3) Shear Resistance - The shear strength should be high to provide stability against sloughing or sliding.

(4) Volume Change - Freedom from large volume changes is required:

a. To prevent shrinkage and cracking.

b. To prevent swelling and "fluffing".

(5) Workability or ease in handling during construction:

a. Ability to take water and to retain it.

b. Freedom from stickiness at optimum moisture.

c. Freedom from large boulders.

d. Ability to support equipment when at optimum moisture.

Extent of Investigations. Extent of investigations of foundation and abutment and borrow pit areas:

(1) Sufficient test holes must be put down to establish the extent and continuity of various strata. In those sites where the surface does not indicate changes in subsurface material or condition, test holes should be put down at changes in slope and at some regular interval to the depth of the expected fill or cut.

(2) Samples should be taken at all changes in soil horizons or strata. Undisturbed samples should be secured when there is doubt as to the stability or permeability of a material.

(3) It is emphasized that all sites in silty, salty, or dispersed soils should be thoroughly investigated.

(4) At all sites, a thorough investigation of the abutments is necessary to indicate the presence or absence of hazardous geologic conditions or unstable soil conditions, both above and in the abutment.

(5) The excavation and sampling of test pits in place of auger holes is strongly recommended in areas of highly stratified heterogeneous (variable) soils on sites for major structures.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Factors and Characteristics to be Investigated

The conditions discussed herein will not be found in all areas. It is believed, however, that a discussion of them will aid in their recognition.

Gypsum and/or Soluble Salt. When the soil in either the foundation or abutments contains more than .50% of either total soluble salt or gypsum, the structure should be designed to compensate for the salt content. Crystalline gypsum in soil seems to build up an abnormal porosity and consequently, very low volume weights. Serious settlement frequently results when saturated "gypy" soils are loaded. These "gypy" soils are often prone to piping. Because gypsum is slowly soluble and unstable, prolonged contact with water often results in the formation of solution channels and/or caverns or crevices.

Dispersion. Dispersed soil is a soil in which the clay readily forms a colloidal solution. Dispersed soils usually have low permeability. They tend to shrink, crack, and become hard on drying and to slake and become plastic on wetting. Percent dispersion represents that portion of the clay (.005 mm) which is easily slaked by water. Dispersed soil conditions in foundations or abutments often results in excessive settlement and failure.

Low Volume Weight. Low volume weight and high porosity often occur in alluvial soils due to processes of sedimentation. As mentioned previously, gypsum can often build up high porosity and low volume weight. With low volume weight soils, abnormal settlement due to consolidation may result from pressure and saturation.

Porous Strata. This term denotes those rapidly permeable strata or zones composed of uncemented cobble, gravel, sand, disintegrated or fractured rock materials, etc. Excessive percolation through these strata may result in piping and failure. Serious and heavy water losses can occur from excessive and rapid percolation through the porous zones. Rapid water movement in porous strata can produce high hydrostatic uplift, which may cause sliding and flotation.

Consolidated (Rock) Materials. Pits or trenches must be excavated or borings made to permit investigation of the underlying foundations. When the geologic materials or conditions are in the least questionable, examination of the site by a competent geologist should be made to provide information with regard to:

(1) Kind and soundness of unconsolidated material or rock. Limestones may go into solution and some shales may weather rapidly, thereby eroding away the foundation or forming crevices.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Factors and Characteristics to be Investigated (cont'd)

Consolidated (Rock) Materials (cont'd)

(2) Dip or strike and stratification of the material. Shale beds which dip downstream can result in failure of a dam through sliding.

(3) Presence or absence of soupy or plastic strata.

(4) Presence or absence of faults of fissures.

Organic Matter. Soils high in organic matter, such as peats or mucks, are often encountered in foundations and/or abutments. These high organic soils are unstable, have very low bearing capacity, and show a high degree of compressibility and expansion.

Investigation of Foundations for Dugouts or Pits. The investigation of soil conditions for a dugout should cover several items. If the water supply is to be from the surface it will be necessary that the seepage rate from the pit be slow. The capacity of a dugout is usually small so seepage loss will have an important effect on the permanency of the supply. The rate of seepage may reduce with age due to silting. If the water supply is from ground water, a porous material is beneficial. It might even be necessary as a maintenance feature to remove silt or an accumulated layer from the bottom and sides after a few years to allow seepage. Investigation should show construction conditions, wetness to hinder equipment or sufficient water for an underground supply.

The standard legend to be used for submitting logs of borings is shown in Part 2 of this Handbook.

3. DESIGN OF EARTH DAMS AND DUGOUTS

Foundations

All steep earth slopes upon which embankment is to be placed should be sloped to a 1 to 1 slope or flatter in order that the fill material may make a proper bond with the foundation and all surface cracks are removed.

Compensatory Measures. There are compensatory measures to overcome weak characteristics of foundations.

(1) Gypsum and/or soluble salt factors may be compensated for by incorporation of impervious blankets or core walls to prevent excessive percolation into the "gypy" soils.

(2) The dispersion factor may be compensated for by the same measures as above.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Foundations (cont'd)

Compensatory Measures (cont'd)

(3) Low volume weight soils may be counteracted by removal of the material, cutoff walls, or blankets to prevent excessive percolation into the soils or broadening the base of the structure to reduce effective weight per unit area of foundation.

(4) Porous strata may be covered by an impervious or less pervious soil blanket. Where it is not possible to completely cut off deep strata and where excessive uplift pressures may develop, drainage or relief wells may be installed to reduce the hydrostatic pressure. For flood water retarding, grade stabilization, or sediment storage dams where there is little danger of the development of uplift or piping and where seepage loss will be of small concern, a positive cutoff may not be needed.

A Core Wall Cutoff. A cutoff wall may be used to reduce the amount of seepage beneath the dam through the foundation, or it also may be used to reduce the pore pressure downstream from the core trench to provide safety against piping or flotations in permeable foundation strata.

It is important to reduce seepage losses to a practical minimum where water is being stored for use such as irrigation. Seepage other than that affecting the stability of the structure is unimportant for most flood water retarding and erosion control dams.

Foundation materials that approach homogenity and are relatively impervious may not require core wall cutoffs where storage of water is not important. A shallow core wall may be used to insure safety from foundation imperfection in the upper 3 - 4 feet.

A core wall cutoff may be used effectively and economically for foundations with a permeable layer or layers to depths of 15 or 20 feet if such permeable material can be economically dewatered to permit construction of the cutoff. For foundations of deeper permeable material, consideration should be given to the use of other methods to accomplish the objective of a cutoff wall.

Foundation Drains. Drainage requirements are dependent upon site factors and the functional requirements of the dam. Drainage is provided to increase the stability of the dam by lowering the phreatic (saturation) line, reducing uplift and increasing the shearing strength of the earth embankment. Drainage also provides for removal of water moving around the end of the dam through the abutments which could otherwise break out at the junction of the downstream slope of the dam and the abutment.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Foundations (cont'd)

Foundation Drains (cont'd)

Requirements for drainage cannot be stated except for specific site conditions. Particular sites may require zoning of fill material, blanket drains, and relief wells, etc. Where the foundation is porous or springs and seeps are present, a system of drains may be needed in the downstream one-third of the dam.

Embankment

There are several factors to consider in the design of an embankment.

Freeboard. Freeboard is the vertical distance from the top of the settled embankment to the water surface in the reservoir when the spillways are operating at design capacity. Consideration will be given to increase the following minimum freeboard when frost conditions or wave action warrant an increase.

(1) Class (a) structures where the product of storage time height is less than 3000 - minimum freeboard 1.0 foot.

(2) Class (a) structures where the product of storage times height is greater than 3000 and all Class (b) and (c) structures - as defined in Washington Engineering Memorandum No. 3, Revised.

Design Height. The design height of a dam is measured on its center line, generally from the top of the dam to the bottom of the valley floor beneath the dam. Definition of valley floor is found in design criteria or specifications.

Embankment Protection from Runoff. High embankments are susceptible to erosion from runoff of rainfall in the faces of the dam. Each face of the dam shall be protected from erosion. When vegetative methods are not considered to be adequate, berms having a minimum width of 8 feet shall be constructed on either or both the downstream face of the embankment at not over 40-foot vertical intervals. These berms shall have a cross section and a bottom slope which will convey runoff water from the face of the dam to paved or sodded gutters located at the junction of the embankment and its abutments.

Rock riprap or a gravel blanket may be used to prevent erosion by runoff on the face of the embankment in lieu of berms. Specifications for the riprap or gravel blanket will be dependent upon the specific site condition.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Embankment (cont'd)

Embankment Protection from Wave Erosion. One of the three alternate methods given below may be used where wave erosion is a hazard.

Alternate No. 1 - A berm having a minimum width of 8 feet is constructed on the upstream face of the embankment at or not more than one foot below the normal pool level. The berm is level in a longitudinal direction and may be flat or have not greater than a 10 percent slope away from the embankment. Appropriate water-tolerant vegetation is planted on the berm. These criteria apply to dams containing a considerable amount of detention and the normal water surface elevation falls some distance below the crest of the emergency spillway. Under conditions where the normal water surface elevation is close to the crest of the emergency spillway, as is the usual case in storage dams, Alternate No. 2 usually applies.

Alternate No. 2 - Riprap for wave protection shall be used to protect the upstream face of the embankment. Other methods of protection may be required where riprap material is not available.

Alternate No. 3 - Special design employing flatter slopes may under some conditions provide adequate protection against wave action.

Settlement. The constructed elevation of the embankment at all sections shall be sufficient to insure that the settled elevation will be greater or equal to the design elevation of the embankment. For Class III embankment an additional 10 percent in height must be added for settlement. For Classes I and II embankment, an additional 5 percent in height will be added. Settlement takes place in the foundation as well as in the embankment.

Determination of Design Requirements. The following minimum conditions are specified:

Conditions or criteria requiring Class I or II embankment. (See page 9-2.)

(1) All dams that are to be constructed as Class (b) or (e) structures as defined in Washington Engineering Memorandum No. 3, Revised.

(2) All structures where the product of storage volume in acre feet and the vertical distance in feet between the emergency spillway crest and the lowest point in the cross section on the center line of the dam exceeds 3000.

(3) All dams over 30 feet in design height.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Embankment (cont'd)

Determination of Design Requirements (cont'd)

The above conditions require soil samples and tests of foundation and embankment materials. Tests should also be made where foundation or embankment materials are shaley or questionable, or where there is saturated alluvial material.

The need for laboratory study and analysis of foundation and borrow materials and for higher quality embankments are particularly dependent upon the judgment of the field engineer. When in doubt, request assistance or submit soil samples for laboratory tests.

It is not the intent to make the above requirements and criteria binding to the point of impracticability. Considerable judgment will need to be exercised in the field. Where structures of comparable size and material have been built and proven successful under conditions similar to and in proximity of the one under consideration, it generally would be considered practicable to build a new structure with specifications similar to those used for the previous structures. Where soil sampling and laboratory tests are not employed, there must be a knowledge of or experience with similar materials so the characteristics and behavior of the materials are known. Where knowledge or local experience indicates critical features may exist, it is the responsibility of the technician who designs the structure to see that adequate investigations are made and adequate standards required.

In general, an embankment designed within the scope and understanding of the Handbook will call for slopes of 3 to 1 upstream and 2 to 1 downstream, standard top width, foundation treatment core wall construction and placement of embankment. Where the need of a given area or condition repeatedly calls for special measures, they will be specified by the responsible engineer and may then become a part of standard operating procedure. Such special measures may include flatter slopes, berms, greater top widths, special compactive methods, moisture control, etc.

Characteristic Analysis of Borrow Materials.

The best materials are those which are graded from coarse sand and gravel through clay. This type of material is best from the standpoint of compacted weight, permeability, stability, and workability. The ideal sandy fill material approximates 60% sand, 30% silt, and 10% clay. The clay limit for an ideal material is generally considered to approximate 25%, or a gradation represented by 25% silt and 50% sand. Addition of gravel up to 30% to this material would increase the compacted weight and impermeability, and the resulting mixture would be very workable if free from stones of over 6 inches in maximum dimension. Heavy clays with the approximate composition of 20% sand, 30% silt, and 50% clay, for use as cores or blankets are to be worked with special precautions.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Characteristic Analysis of Borrow Materials (cont'd)

Soils containing 40 percent or more silt generally are characterized by low shearing resistance and therefore are prone to slough or slide when loaded and saturated. Some soils with high lime contents have been found to be suitable for borrow. Such soils may lend themselves readily to compaction and retain a high degree of workability even when wet. When limey soils are thoroughly wet rolled, a sort of "setting up" occurs and the resulting fill is very dense and compact. Gypsum in borrow materials is not so detrimental as in foundation materials. Borrow materials containing over 1.5 percent soluble salts should be excluded if possible. Soils with 0.5 to 1.5 percent total salts must be thoroughly compacted, and in placing care must be exercised so that large zones of such material are not segregated in any portion of the dam. Dispersed soils become unstable when wet, and are prone to crack or shrink severely when dry. Dispersed soils often require special design and should be avoided if other material is available. Soils with high silt content or high clay content, usually yield low compacted weights and therefore the embankment design must be adjusted accordingly.

In the light of the foregoing discussion, it should be evident that structures must be designed according to the materials at hand. Any borrow material selected on the basis of field determination may prove to be undesirable when tested in the laboratory.

Flood Flow and Annual Yield

See Part 3 for estimating surface runoff and annual yield. In general, the earth dams and connected structures designed within the scope of this Handbook will be based on a peak flow of not less than 25-year frequency.

Design Features Related to Storage

For permanent storage of livestock water, the minimum depth will depend on site and climatic conditions. A minimum of 10 feet is generally preferred.

Where permanent storage is planned for fish, a minimum depth of 10 feet should be provided. A deep pond of small surface area will be less subject to evaporation. To avoid the growth of aquatic plants which harbor fingerlings and thereby cause overpopulation, no shallow areas with flat slopes should be allowed.

Where storage is desired it is necessary that the lands and drainageways in the watershed be stable. At least 75 percent of the area should be in permanent vegetation or under conservation land treatment, with 100 percent the goal. In addition to the storage designed for water, a definite volume is required for silt. This space will insure the proper functioning of the structure throughout its life.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Design Features Related to Storage (cont'd)

The cost versus benefit of the storage proposed should be carefully weighed. An increase in the amount of storage can decrease flood damage downstream, gives greater protection to the emergency spillway because of less frequent use, or insures a greater supply of stock or irrigation water. Against this must be charged the increased damage within the pool area, the cost of additional embankment and other construction items and maintenance as well as restrictions imposed by state law.

The volume of storage may be measured by one of the methods of survey described in Part 1 of this Handbook.

The use of storage in design can be made by several methods. The development of hydrographs are described in Part 3.

Principal Spillway (See Figure 9.1)

Function. The function of the principal spillway is to convey in a safe and non-erosive manner all discharges equal to or less than the design discharge of the principal spillway from the reservoir to the natural drainageway. The principal spillway may be reinforced concrete sectional pipe supported by cradle or bedding, monolithic reinforced concrete conduit, welded steel pipe, corrugated metal pipe, or close riveted and asphalt dipped corrugated metal pipe with watertight connecting bands. Generally this spillway is a drop inlet through the embankment but it could be a chute or drop spillway constructed of concrete. Selecting material for the principal spillway should be based on the expected life of the structure.

Alignment. The alignment of the principal spillway should be dictated by the necessity for a suitable foundation and to receive and discharge flow in the most suitable manner. For location, the structure may be placed in original ground where dry and stable or on thoroughly compacted fill. It is not wise to place the pipe on compacted embankment for a part of its length with the remainder on original ground. If it is imperative that a portion be on compacted fill and the remainder on original ground, at least two feet over excavation should be made in original ground and this void filled and compacted in the same manner as the rest of the fill to equalize conditions throughout the length of the pipe.

Sometimes the location of the principal spillway seems most suitable along one bank of the gully. The outlet should be nearly parallel with the channel downstream to minimize scour in this area. If the dam site will not allow straight horizontal alignment of the principal spillway a slight bend may be used when prior approval has been given by the responsible engineer. When conduit cuts an angle other than 90° with the center line of the embankment, the increase in length must be computed.

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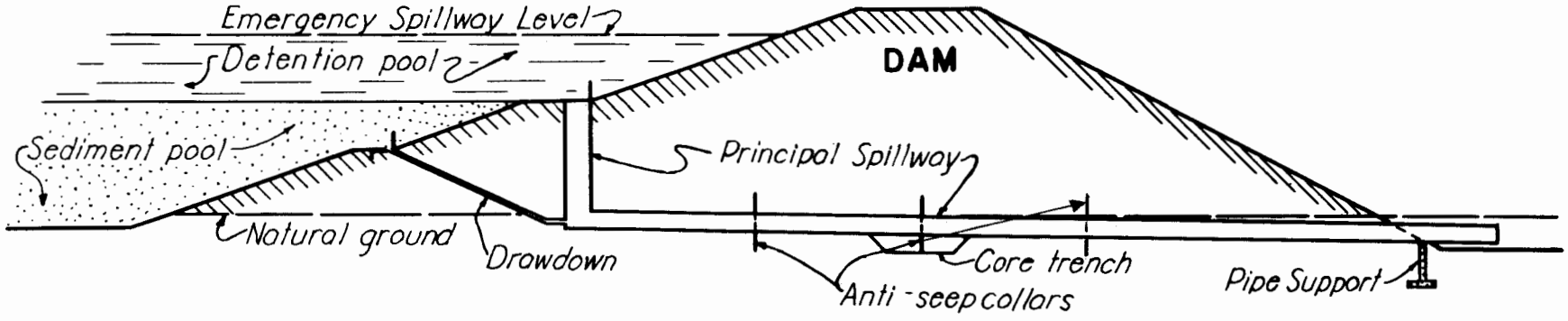


TYPICAL SECTION OF A FLOODWATER RETARDING STRUCTURE

SHOWING PRINCIPAL SPILLWAY

Figure 9.1

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Principal Spillway (cont'd)

Diameter of Outlets. The minimum size of gated outlets shall be based on the discharge capacity required to meet downstream interests.

Trash Racks at Entrance of Principal Spillway. Trash racks shall be designed to provide protection against clogging of the inlet or the spillway conduit proper.

Anti-Vortex Device. All principal spillways shall have adequate anti-vortex devices.

Durability of Materials. All the component parts of the principal spillway conduit except the cantilever outlet shall be of approximately equal durability.

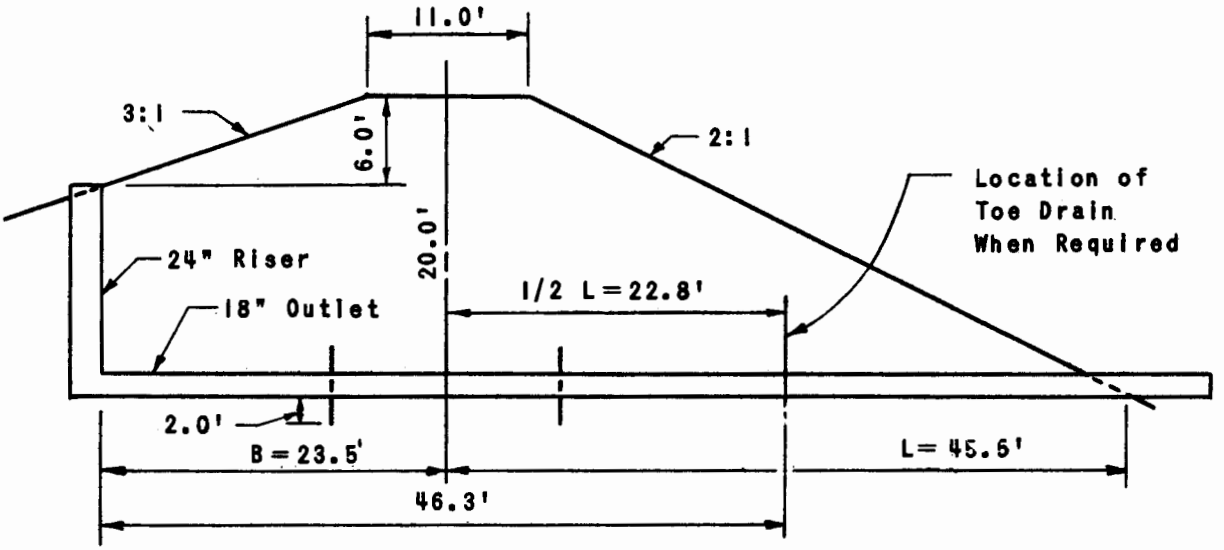
Cantilever Outlets. Cantilever outlets of principal spillway conduits shall be supported on bents or piers and shall extend a minimum of 5 feet beyond the bents or piers which shall be located at or below the intersection of the downstream slope of the earth dam embankment and the grade line of the channel or waterway below the dam. The invert of the cantilever outlet at its lower end shall be at least one foot above the grade of the downstream channel. While it is unwise to have an outlet set too high, it is far more simple to correct than one that is too low. An artificial stilling pool will be excavated when soil conditions at the downstream end of the cantilever outlet indicate that a stilling pool will not be readily formed by flows without extensive erosion of side bank or the constructed embankment.

Anti-Seep Collars. All conduits through or under earth embankments, foundations, and abutments shall be protected with anti-seep collars. This includes pipelines, utility lines, etc. The minimum number of anti-seep collars shall be determined by the size of collars and the length of that portion of the conduit which lies in the saturated zone of earth embankment. That portion of the barrel in the saturated zone shall be considered to extend from half way between the center line and the downstream toe of the embankment, upstream to the inlet of the barrel or the base of the riser, whichever is applicable. The number and size of collars, spaced on not to exceed 25 foot centers, shall be such that their projecting length, times two, is equal to or exceeds 15 percent of the length of the barrel lying in that portion of the saturated zone being considered. (See Figure 9.2.)

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Principal Spillway (cont'd)

Anti-Seep Collars (cont'd)



Location of Anti-seep Collars and Toe Drains

Figure 9.2

Required creep distance = (B + 1/2 L) x 1.15 = 46.3' x 1.15 = 53.2'

Additional creep distance required 53.2' - 46.3' = 6.9'
Use two 2.0' collars = 8.0'

Capacities. For capacities of pipe "drop-inlet" culverts, see the Head Discharge tables for Weir flow, orifice flow, and pipe flow, in Part 15 of this Handbook.

Principal Spillway of a Grade Stabilization Dam. The capacity of the principal spillway of an erosion control dam will be dependent upon the protection necessary for the emergency spillway. The following general specifications apply:

(1) The principal spillway (pipe or conduit) will have a minimum capacity equal to or greater than 25 percent of the peak flood flow based on a 25-year or greater frequency storm except as qualified by (2).

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Principal Spillway (cont'd)

Principal Spillway of a Grade Stabilization Dam (cont'd)

The following table is a guide for determining the percentage of the peak flow to be handled through the principal spillway by classifying the quality of the emergency spillway without considering spillway storage.

Quality of the emergency spillway	Percentage of peak flow to be handled by principal spillway	Frequency of flow expected in emergency spillway	General condition of emergency spillway
Very good	25%	Once or twice per year	Smooth sod
Good	35%	Every 2 years	Sod, small drop
Fair	50%	Every 3 or 4 years	Good spread, over shrubby banks
Poor	75%	Every 8 years	No spread, over raw bank
Very poor	100%	Every 25 years	Over sand bank or in building lots.

(2) Where practicable, temporary storage (between the crests of the principal and emergency spillways) may be used in conjunction with the principal spillway to provide control of outflow. The combination of outflow through the principal spillway and the temporary storage shall provide disposition for at least 25 percent of the peak flood flow to meet the minimum requirement. Conservation land treatment must be such that there will be no significant loss of the temporary storage volume.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Principal Spillway (cont'd)

Principal Spillway of a Grade Stabilization Dam (cont'd)

When temporary storage is considered, the effects can be determined by the following formula:

$$Q_o = Q_i\left(1-\sqrt{\frac{V_s}{V_f}}\right) \text{ - - - - - - - - - - - (1)}$$

or

$$V_s = V_f\left(1-\frac{Q_o}{Q_i}\right)^2 \text{ - - - - - - - - - - - (2)}$$

where V_s = volume of detention storage in reservoir

V_f = total storm runoff

Q_i = inflow peak rate

Q_o = outflow peak rate

In solving the formula, use the situation where the runoff from a selected frequency storm just fills the detention reservoir to the emergency spillway level. The detention storage (V_s) is then fully operative. Also, the peak outflow rate (Q_o) is the principal spillway flow (pipe flow) with the head causing flow at emergency spillway elevation.

Theoretically, the value Q_o in formula (1) more nearly reflects average pipe flow than peak pipe flow. However, based on actual flood routing, when the ratio Q_o/Q_i is small, Q_o can be taken as the peak outflow rate. This gives a percent error small enough to be relatively insignificant. When Q_o/Q_i exceeds 0.45, the formula gives errors of 5 percent or more. Therefore, the formula should be used only when:

$$Q_o/Q_i \leqq 0.45$$

or

$$V_s/V_f \geqq 0.3$$

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Principal Spillway (cont'd)

Principal Spillway of a Floodwater Retarding Dam. The required capacity of the principal spillway of a floodwater retarding dam is dependent on

(1) The benefits that accrue due to reduction of discharge.

(2) The needs to satisfy downstream water use.

(3) The damages resulting from storage and prolonged outflow.

(4) The effect of significant runoff from two or more consecutive storm events during the time required to discharge the detention storage.

(5) The capacity of the downstream channel.

The crest of the inlet of the principal spillway shall be placed at the computed elevation of the sediment pool. Gated openings or ports placed below the elevation of the sediment pool do not represent the crest of the principal spillway.

Principal Spillway of a Storage Dam. When an erosion problem exists in connection with the location, or if one will be created in the construction, of a water storage dam, a principal spillway will be designed to provide protection for the erosion problem as well as the facility.

In lieu of a principal spillway, trickle tubes are often used in water storage dams. Criteria for their use and required capacity are specified in technical standards of specifications. Discharge capacities for pipe can be found in Part 16 of this Handbook.

Gated outlets provided in irrigation storage dams must be of sufficient size to pass the required irrigation stream and to provide for other downstream interest. Figure 9.3 shows a typical installation of this nature.

A stock watering device to feed a tank below a storage reservoir is often recommended to assure a relatively pure stock water supply. In these instances the impounded area is fenced to prevent pollution. For a typical installation see Figure 9.4.

Principal Spillway for Dugouts. Where a dugout is constructed with a part of its capacity above ground, the criteria for storage dams should be used to plan means for outflow of excess water.

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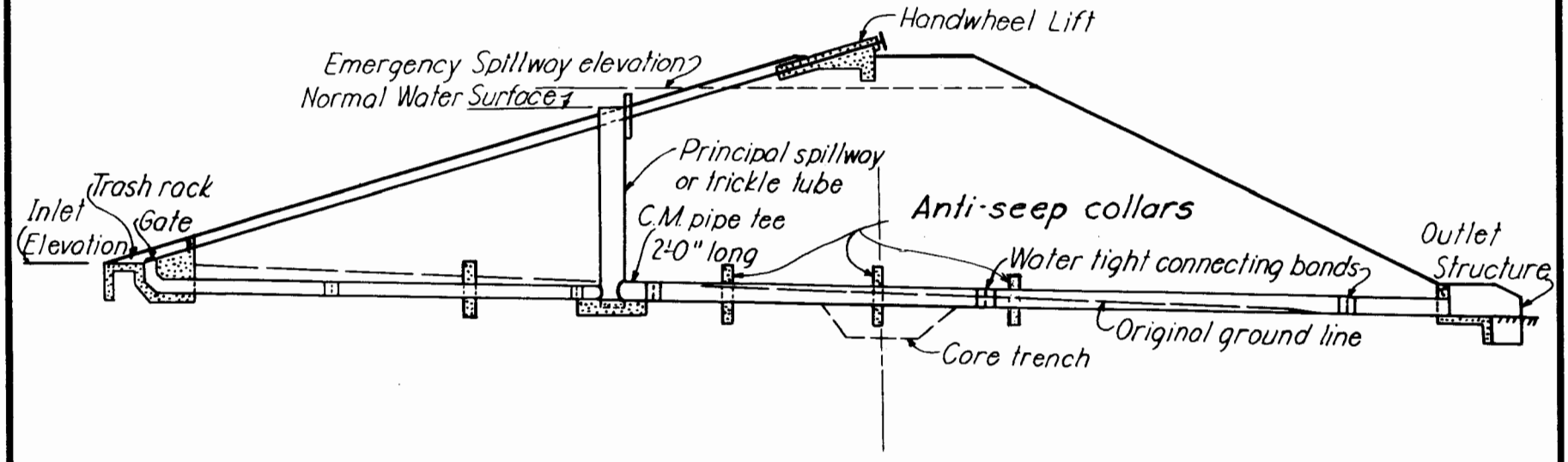

TYPICAL SECTIONAL ELEVATION OF STORAGE DAM ALONG CENTERLINE OF PRINCIPAL SPILLWAY AND GATED OUTLET

Figure 9.3

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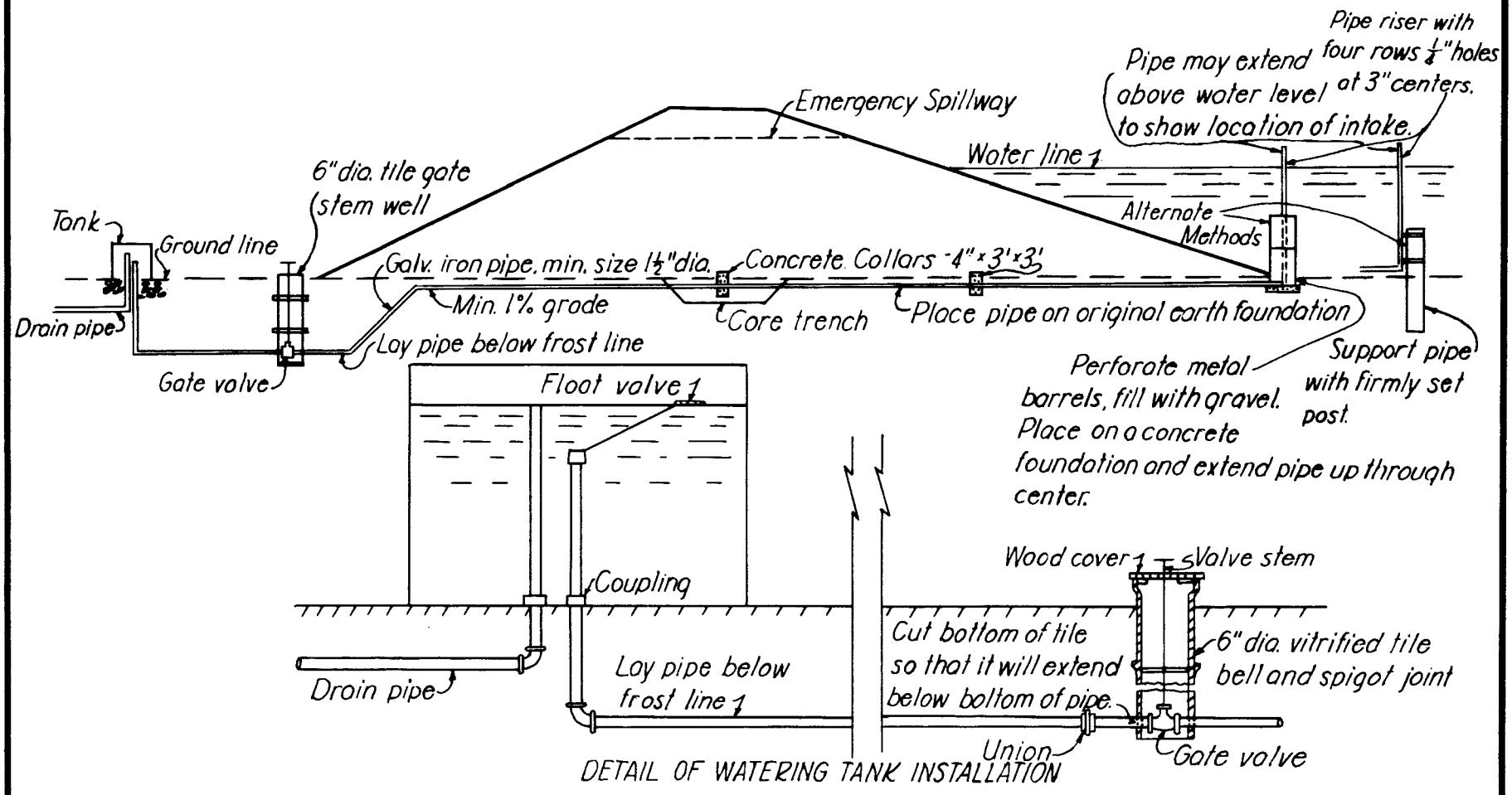

Pipe riser with four rows ¼" holes at 3" centers.
Pipe may extend above water level to show location of intake.
Emergency Spillway
Water line
6" dia. tile gate stem well
Tank
Ground line
Alternate Methods
Galv. iron pipe, min. size 1½" dia.
Concrete Collars 4" x 3' x 3'
Min. 1% grade
Core trench
Place pipe on original earth foundation
Drain pipe
Lay pipe below frost line
Support pipe with firmly set post.
Gate valve
Perforate metal barrels, fill with gravel. Place on a concrete foundation and extend pipe up through center.
Float valve
Wood cover
Valve stem
Coupling
Cut bottom of tile so that it will extend below bottom of pipe.
6" dia. vitrified tile bell and spigot joint
Drain pipe
Lay pipe below frost line
Union
Gate valve
DETAIL OF WATERING TANK INSTALLATION

TYPICAL STOCK WATER TANK INSTALLATION

Figure 9.4

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Emergency Spillways

The term emergency spillway as used in this Handbook denotes any spillway other than a principal spillway or trickle tube. Other writings on the subject of dams may refer to such spillways, under certain conditions, as secondary, auxiliary, or vegetated spillways. In the majority of cases the emergency spillway will cut through unconsolidated material which is to be seeded and vegetated. It may be excavated in rock or constructed of compacted embankment.

The function of emergency spillways is generally to assist a principal spillway in conveying runoff safely past a dam. How much and how frequent flow the spillway can carry is one of the problems of design. Some criteria has been shown under the subject of "Spillways". The emergency spillway should be designed to handle, as a minimum, the 25-year peak flood flow. On sites where construction will require excessive yardage or cause heavy cuts with long steep side slopes into the spillway area, the emergency spillway capacity may be decreased below the 25-year frequency by that amount handled by the principal spillway. Under such conditions an emergency spillway must be designed to not less than 50 percent of the peak flow of a 25-year frequency storm without overtopping the dam. Snow problems should be considered in locating spillways.

The emergency spillway is composed of an inlet channel and an exit channel which are coincident at a common section known as the control section. The control section is that section of the spillway beyond which the slope of the channel is equal to or greater than critical slope and back of which the slope is less than critical slope. The following factors should be considered in the design of emergency spillways.

(1) The channel should be formed within undisturbed or compacted earth or rock and the water surface under maximum discharge be confined by undisturbed earth or rock or carefully constructed and compacted levees of safe proportions. In no case should the water surface be permitted against loose uncompacted fill.

(2) The difference in elevation between the crest of the emergency spillway and the principal spillway shall be sufficient to make the principal spillway operate at design capacity.

(3) Curvature of the spillway alignment is permissible above the control section. Below the control section where supercritical flow exists the channel must be straight in alignment to a point far enough below the earth dam embankment to insure that any flow which might escape from the exit channel cannot do damage to the embankment.

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Emergency Spillways (cont'd)

(4) Unless compensating features exist or are added, the farther downstream the control section is located, the higher is the required stage in the reservoir for any given discharge because of the increase in head loss in the inlet channel. This requires an increase in the elevation of the embankment and higher cost.

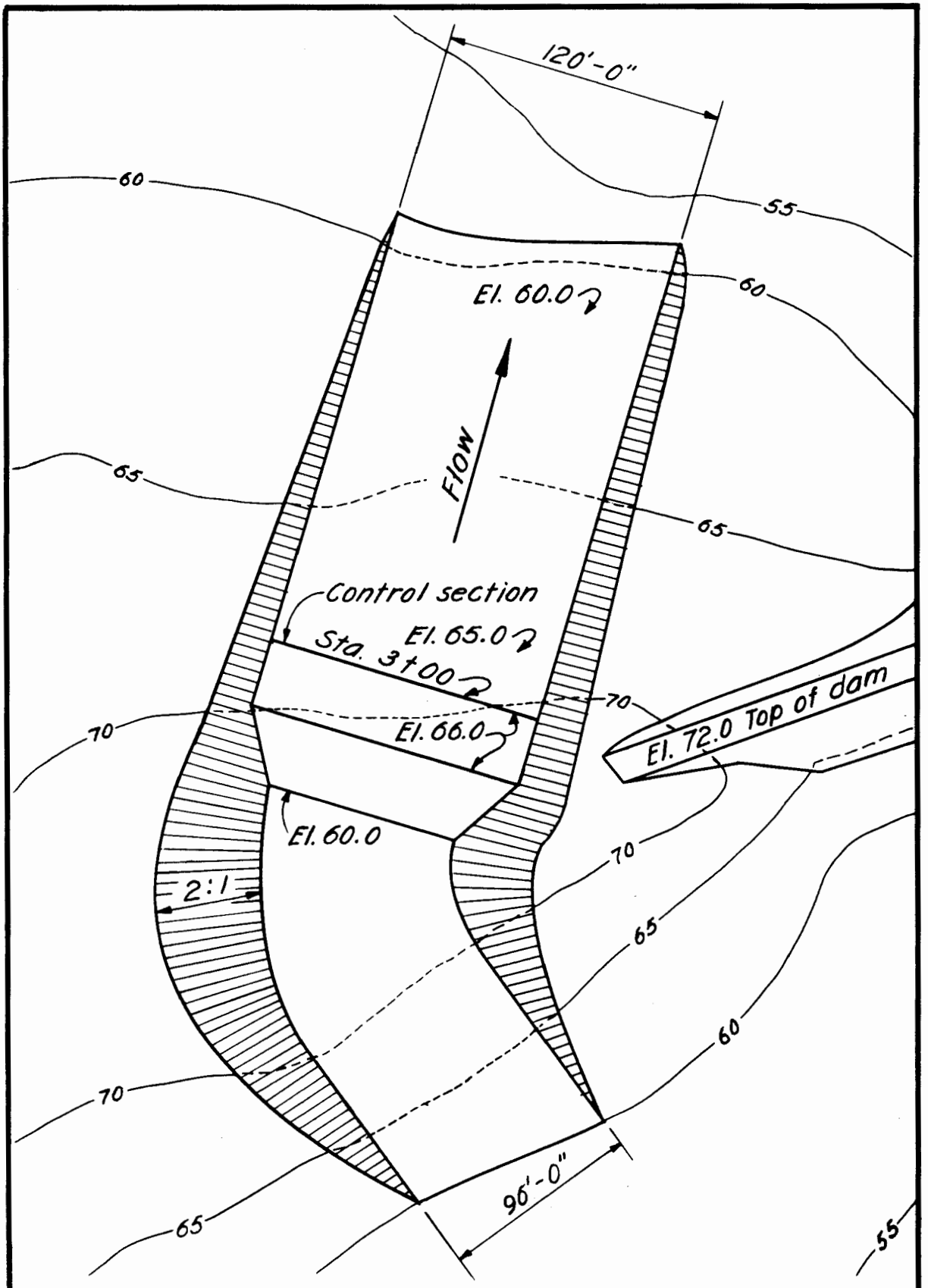
(5) The cross sectional area of flow in the inlet channel should be large in comparison to the flow area at the control section so as to minimize the losses in the inlet channel. This increased flow area may be obtained by increasing the depth or the width or a combination of the two.

(6) The earth spillway above the control section should be constructed with an ascending slope from the reservoir. The channel may be deepened to increase flow area and reduce friction loss by the construction of a forebay. This may be accomplished by inserting a short reach on a 10 to 1 slope. Where the depth of the channel varies as through the 10 to 1 slope, the bottom width of the channel should be changed to avoid abrupt changes in the configuration of the sloping channel banks. For example, if the width of the channel bottom just downstream from the 10 to 1 slope were 120 feet, the channel side slope were 2 to 1, and the drop through the 10 to 1 bottom slope were 6 feet, the bottom width of the channel just upstream from the 10 to 1 bottom slope should be 120 - 2(2x6) = 96 feet.

A uniform transition should exist between these two bottom widths. See Figure 9.5. Figure 9.6 shows the profile of this spillway. Figure 9.7 shows the plan view of a spillway, with an inlet section which has both a horizontal flare and an ascending grade. See Figure 9.8 for a profile of this typical plan.

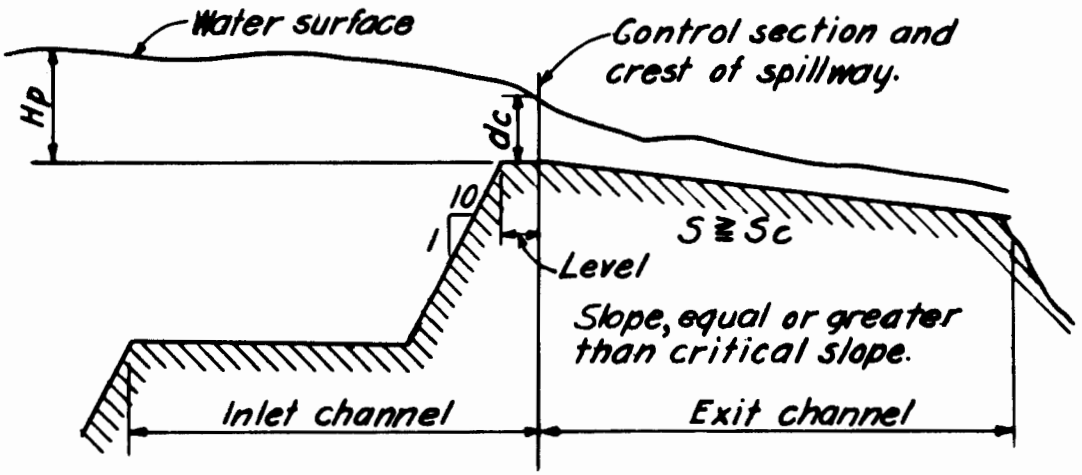
(7) If a road must cross a spillway it should be at a point at least 20 feet upstream from the control section and preferably across a deepened part of the inlet channel. Where dams are used for roads, special provisions must be made for spillway crossings.

(8) Fences should be kept out of the spillway if at all possible. If it is absolutely necessary to cross the spillway with a fence, suspended water gates that will rise and float on the surface of the water should be provided and kept in good repair, or the fence should be located at a low elevation in the inlet channel just above the normal pool level, so that debris will float over it when the emergency spillway begins to function.



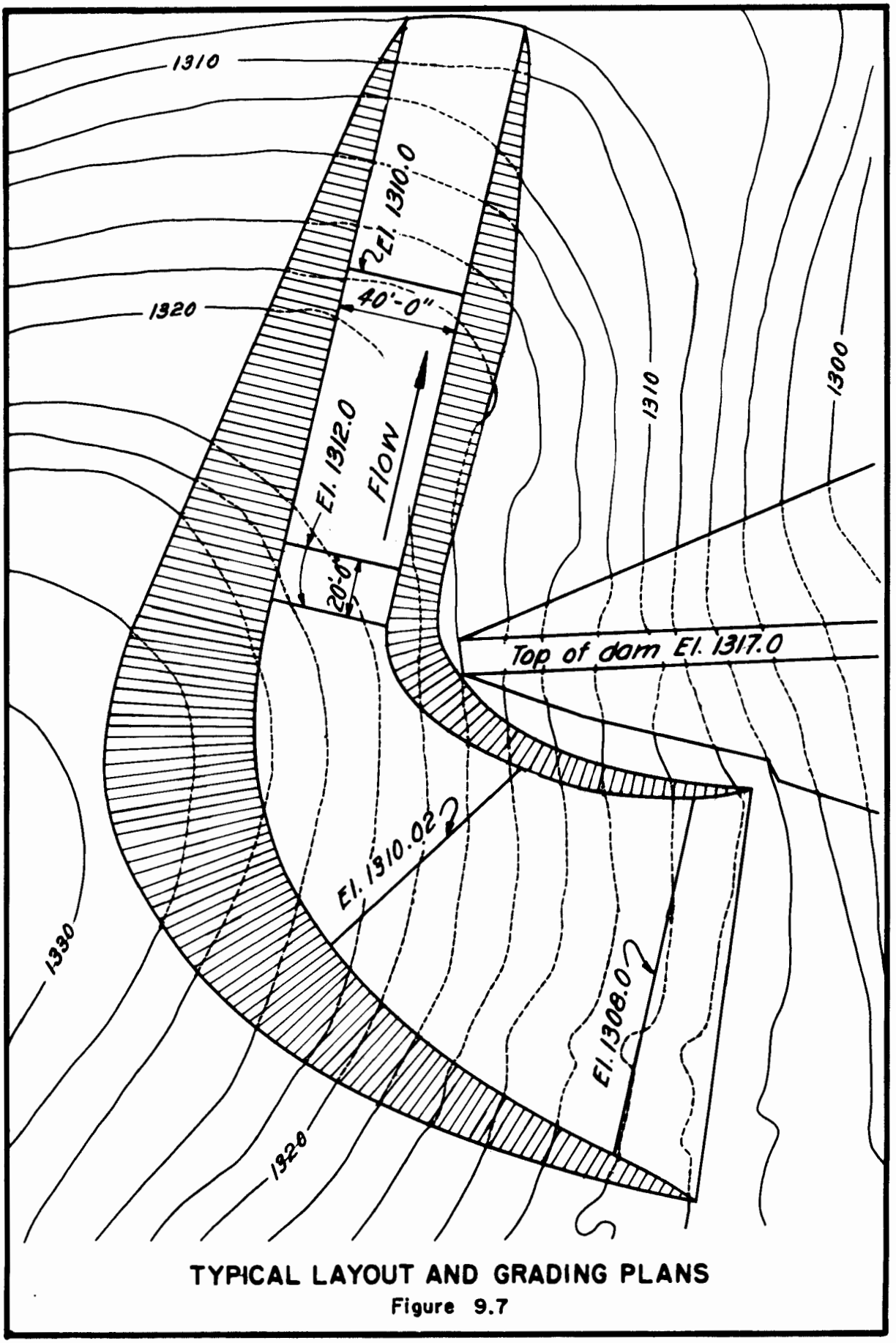
TYPICAL LAYOUT AND GRADING PLANS

Figure 9.5



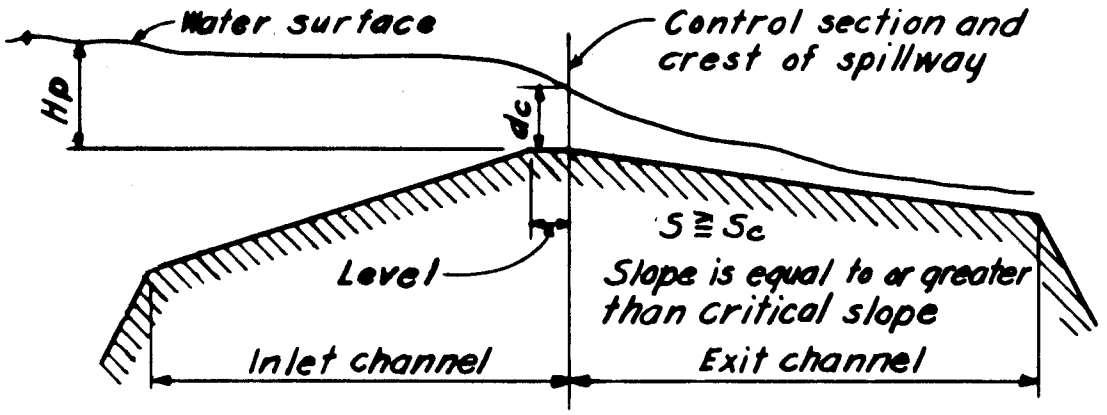
TYPICAL CONDENSED PROFILE ALONG
CENTER LINE OF SPILLWAY

Figure 9.6



TYPICAL LAYOUT AND GRADING PLANS

Figure 9.7



TYPICAL CONDENSED PROFILE ALONG
CENTER LINE OF SPILLWAY

Figure 9.8

3. DESIGN OF EARTH DAMS AND DUGOUTS (CONT'D)

Emergency Spillways (cont'd)

(9) The grade of the exit should be sufficiently steep to insure supercritical flow for 25 percent of the design discharge used to determine the capacity of the emergency spillway.

(10) The depth of flow in the control section of the emergency spillway should be kept as low as possible, considering other conditions, and should not exceed 3 feet unless some very critical need exists. This restriction arises from the velocities and scouring action which accompany greater depths as they pass through critical sections and onto steeper slopes.

Figures for capacities of emergency spillways will be found in Part 16 of this Handbook.

Design of Dugouts

A dugout should be provided with one or more entrances sloped to 4 to 1 or flatter to permit stock to utilize the water at any level. The remaining sides can be made steeper, but ordinarily not more than 2 to 1 since most soils, when saturated, are not stable on steeper slopes.

The excavated material may be wasted around the edges or used to build up dikes to increase impoundage by storing water above the excavation. A berm of at least 10 feet in width should be left between the excavation and the spoil or embankment.

Where a dugout is constructed with part of its capacity above ground, the criteria for storage dams should be used.

Fencing and Seeding

Earth dams and spillways or dugout embankments or spoil banks should be vegetated with recommended grasses as soon as possible after construction. If necessary to protect the seeding, the area should be fenced to exclude livestock.

4. LAYOUT

Layout of an Earth Dam

Structures Designed Before Layout. For these structures, the location of the fill and emergency and primary spillways must be transferred from the plan to field points. Slope stakes and elevation stakes shall be set as needed. See Part 1 for examples of notekeeping and staking.

4. LAYOUT (CONT'D)

Layout of an Earth Dam (cont'd)

Structures Designed at Time of Layout. These normally are small or standard type structures. See Part 1 for staking of embankment and spillway. Data sheets, as shown in Part 2, are utilized instead of field notes in some instances. Principal spillways, trickle tubes, or gated outlets shall be staked for alignment and elevation.

Computation of Quantities. For computation of quantities of embankment the center line fill height may be used with the horizontal distance to the upstream and downstream toe to find the end area from the Earth Work Computation Tables. For cross sections where the ground surface perpendicular to the center line of dam is irregular, such as in the raising of an old dam or construction at an overfall, the cross sections may be plotted and the area determined by use of a planimeter or calculating machine.

Computation of yardage for major structures should be based on the foundation as it is ready for embankment, minus strippings and other material necessary to prepare minimum slopes within the confines of the dam foundation. When applicable, separate cross sections will be used to show core trench excavation, emergency spillway excavation, and dike or wing fill.

Layout of a Dugout

Slope stakes and cut stakes shall be set and recorded according to the principles outlined in Part 1. If the topography is very irregular, cross sections should be taken to provide an accurate measurement of the yardage. Adjacent cross sections should be within 10-20 percent of equal area when yardage is computed by the end area method. Yardage may be calculated by the prismoidal formula. Special precautions must be taken in applying this formula when the land surface varies more than 2 feet in elevation within the dugout area.

The prismoidal formula is: $$V = \frac{1/6\ h\ (P_1 + 4M + P_2)}{27}$$

where V = volume in cubic yards

h = total depth in feet

P_1 = area of top in square feet

P_2 = area of bottom in square feet

M = area at 1/2 h in square feet

(The mid-area must be measured, not averaged, between the top and bottom, if it is to be significant.)

5. CONSTRUCTION

Foundation

The following items must be considered in the preparation of the foundation:

(1) All material containing any appreciable amount of organic matter should be removed. This material may be used for a top dressing of the embankment and spillway slopes to provide a more fertile base for vegetation.

(2) Stumps and roots over 2 inches in diameter in the area must be grubbed to a depth of 3 feet. If they lie within a core trench over 3 feet deep they will be grubbed to the elevation of the bottom of the core trench.

(3) Loose rock larger than six inches in maximum dimension shall be removed from the foundation area.

(4) All steep earth slopes within the confines of the dam should be sloped to a minimum of 1 to 1 to provide a proper foundation. Earthen materials depend mostly on gravity for their stability. If any shrinkage takes place it would leave a cleavage along a vertical or near vertical wall.

(5) No material should be placed on a frozen or boggy foundation.

(6) If the stripped foundation has had time to dry out it should be scarified before any material is placed to facilitate bonding the new material to the old. It may also be necessary to wet the foundation for the same purpose.

Core Trench. The core trench should be excavated with approximately an 8 foot bottom width and to the depth as shown on the plan or where necessary to reach impervious material. It shall extend the full length of the dam and have side slopes no steeper than 1 to 1. If the core trench material is suitable it may be used in the embankment. The volume of the void to determine the quantity of backfill may be measured by cross sections and planimetered end areas or by a prescribed section. The core trench shall be backfilled with select material in the same manner as that specified for the rest of the embankment.

Foundation Drains. Where called for on the plans or where preparation of the foundation uncovers seepage, foundation drains should be constructed to intercept the seepage and conduct it safely beyond the downstream toe of the dam. This will keep the downstream slope of the dam dry and stable. These drains will be a trench having minimum dimensions of 18 inches wide and 18 inches deep, and filled with well-graded gravel or crushed rock. In some instances, gravel-packed pipe drains are utilized. The first cover over gravel drains should be placed carefully to avoid damage to the cross section of the filter. See Figure 9.2 for recommended location of toe drains.

5. CONSTRUCTION (CONT'D)

Construction of the Embankment

The material used in the embankment shall be free from sod, roots, brush, stones over 6 inches in diameter, frozen chunks or any other objectionable material. Placing and spreading shall be in 6 to 8 inch horizontal layers starting at the lowest part of construction. Where possible, these layers shall extend over the full area of the fill. The distribution and gradation of materials throughout the fill shall be such that there will be no lenses, pockets, or layers of material differing substantially in texture or gradation from the surrounding material. Where Class I or II embankment is specified, compaction equipment shall be used to produce the required density. Where moisture is not adequate it shall be added in the borrow pit or on the fill. It may be necessary to mix the material to insure uniformity of material and/or moisture. When the material is too wet, it shall be dried before compacting. Special care must be taken to obtain proper compaction around rock, against steep abutments, etc.

Borrow Areas

The borrow material should be obtained from a site which is not only situated conveniently for hauling, and which has proper material but is in a position to leave a satisfactory area afterward. It should be at least 25 feet out from the front slope of the dam. No borrow should be taken where it will leave ugly scars on steep slopes, places difficult to stabilize and vegetate, or which are unsightly to view. These high pits are frequently economical for a contractor to use but are no benefit to the land. The best source for borrow, since it frequently has the additional advantage of adding to the storage available for sediment or water, is upstream from the dam, below the waterline. The material from an excavated spillway should be used if suitable. It is a good plan to use this material reasonably early in construction so that none need be wasted and thereby add to the total cost.

Principal Spillway and Outlet Conduits

The principal spillway shall be installed in accordance with the plans and specifications.

Corrugated Metal Pipe Outlet. Just before the pipe is placed, the bottom of the pipe trench shall be shaped to fit the outer circumference of the pipe in such a manner that at least 1/6 the circumference shall bear against solid undisturbed ground or compacted material for its entire length. Because the foundation will settle more in the center or high portion of the dam it is a good practice to slightly arch the pipe initially to allow it to come to a more nearly uniform gradient after

5. CONSTRUCTION (CONT'D)

Principal Spillway and Outlet Conduits (cont'd)

Corrugated Metal Pipe Outlet (cont'd)

settlement. Where the outlet pipe is on from 1% to 2% gradient this may be simply done by placing the section from the upstream end to center line of dam on approximately a zero gradient with the total grade initially constructed from the center line to the outlet. Where unsuitable material is found it should be excavated and replaced with compacted selected material.

The circumferential joints should be placed so the outside laps are upstream (proper shingling for waterflow) and longitudinal joints are at the sides.

In banding corrugated metal pipe, a heavy asphalt mastic impregnated with asbestos or other filler material should be generously applied to the inside of the band and the outside ends of the pipe so that when the band is drawn tight the mastic will be extruded, providing a filled joint. Specially designed water-tight connections will be accepted if properly installed.

Concrete Box or Pipe Outlet. Construction of concrete pipe and cradle or monolithic concrete box outlets will require more detailed specifications and design than is covered by this book.

Anti-Seep Collars. Anti-seep collars, either metal or concrete, shall be constructed where shown on plans or according to specifications. For dams of considerable height with corrugated metal pipe, concrete collars may not allow sufficient deformation of the section of pipe within the collar in relation to adjacent sections. For this reason metal collars are usually specified under these high embankments.

Where metal collars (diaphrams) are used, care must be exercised to insure water-tightness. A heavy asphalt mastic impregnated with asbestos or other filler material should be used between all joined surfaces.

Pipe Supports. Pipe supports will be constructed where shown on the plans or where, in the opinion of the designing technician, they are necessary to insure protection of the downstream toe of the dam from erosion. Concrete, steel, or treated timber may be used.

Concrete. Concrete for the base of the riser, anti-seep collars or pipe support shall conform to the standard for Class "B" concrete as set up in the Standard Technical Specifications.

5. CONSTRUCTION (CONT'D)

Principal Spillway and Outlet Conduits (cont'd)

Backfill. After the outlet pipe, anti-seep collars, base for riser and appurtenances have been installed and inspected, backfill of selected earth material should be placed to a height of two feet over the top of the pipe. The backfill should be made in 4 inch layers with each layer thoroughly compacted by hand or mechanical tampers.

Earth backfill should be uniformly compacted directly to all concrete or metal and earth surfaces. If the pipe is not entrenched it will likely be expedient to raise the adjacent embankment concurrently with the structural backfill.

Care should be taken to insure the backfill being placed concurrently on both sides of the structure so as to prevent displacement by unequal side thrusts.

If sufficient moisture is not present in the backfill material it should be added in the required amounts.

No backfill should be placed against earth retaining concrete structures for 7 days or until the concrete has attained a strength of 2,000 pounds per square inch. Concrete placed in cold weather may require longer periods to attain required strength.

Livestock Watering Facility

For details of construction of a typical stock-watering device see Figure No. 9.4.

Excavation of Dugouts

A bulldozer is probably the most efficient piece of equipment for excavating a dugout and moving the material the short distance required. The flat slopes to be used by livestock for access to the water provide the ramp for removing the material.

Fencing

When fencing is required use standard plans.

6. MAINTENANCE

Maintenance of Embankment

Unless some unusual development occurs the maintenance necessary for an earth embankment is very minor. If excessive seepage develops in the downstream toe or if sloughing of the downstream slope of the embankment or of the abutments should occur, it should be brought to the attention of the Area Engineer.

As mentioned before, the fill should be seeded to suitable grasses. However, if conditions are not favorable for grass, other vegetation in the form of weeds will develop to help protect the surface. The latter are less desirable from appearance but will assist until grass can be started.

If traffic from livestock tends to damage the embankment, they should be fenced out.

Maintenance of Emergency Spillway

Where subject to travel by livestock the emergency spillway should be fenced. If fenced, establishing vegetation will be the primary problem of maintenance in the emergency spillway. Once a good stand is established no further trouble should be experienced. If erosion occurs before vegetation is established, or by unusual flows afterward, the damaged areas should be repaired and reseeded as quickly as possible.

The outlet structure of the principal spillway through an earth dam should be practically trouble-free if properly maintained. It should be inspected periodically, particularly following heavy discharges, to insure the removal of debris from the trash rack or obstructions that might have become lodged in the riser or barrel. Beaver have been known to plug drop inlets in wet areas.

7. EQUIPMENT

Engineering Equipment

For investigation of the site and of borrow material, soil sampling equipment will be needed, i.e., a soil auger, a spade, or under certain conditions, power drilling and sampling equipment. For finding and checking moisture-density relations, testing equipment will be needed.

Construction Equipment

For most earth dams and dugouts heavy earth moving equipment will be needed. Where compacted embankments are required, compaction equipment also will be necessary.

7. EQUIPMENT (CONT'D)

Construction Equipment (cont'd)

A bulldozer is an economical earth mover for short distances and can be used to place and spread borrow materials in a satisfactory manner. However, it has fallen into disrepute because of the too common practice of pushing everything into the embankment with earth materials; i.e., brush strippings, etc. In addition, operators often fail to spread the load but leave it in a pile which does not lend itself to developing adequate or consistent densities.

Also contrary to the belief of some people, a track-type tractor is not a good compactor. The rubber-mounted dozers may produce better densities by their travel. This deficiency is overcome where compaction equipment is used for compaction.

Because of these inherent weaknesses in the bulldozer operation it has been found necessary in general to require scraper wagons for placing the borrow material in earth embankments.

Where an earth dam is to be placed in a narrow, deep gully, it is usually more simple, cheaper, and better to prepare the site with a dragline. A dragline can remove the strippings and waste material clear of the area, whereas a bulldozer often only mixes it up and leaves it in the way.

A dragline or boom truck is very convenient to help install corrugated metal pipe and appurtenances.

CONTENTS

PART 10

SPRING DEVELOPMENT AND HYDRAULIC RAMS

Subject	Page
SPRING DEVELOPMENT	
1. General	10-1
2. Dependability	10-1
3. Collection	10-3
4. Spring Boxes	10-3
5. Delivery and Overflow Pipes	10-5
6. Protection	10-6
HYDRAULIC RAMS	
1. General	10-6

LIST OF FIGURES

PART 10

SPRING DEVELOPMENT AND HYDRAULIC RAMS

Figure Number	Title	Page
10.1	Typical Types of Springs - - - - - - - - - - - - - - - -	10-2
10.2	Sample Spring Development- - - - - - - - - - - - - - - -	10-4
10.3	Approximate Capacity of Hydraulic Rams - - - - - - - -	10-7
10.4	Diagrammatic Sketch of Ram Installation- - - - - - - -	10-8

PART 10

SPRING DEVELOPMENT AND HYDRAULIC RAMS

SPRING DEVELOPMENT

1. GENERAL

The development of a spring involves the construction of a collection system, placement of a delivery pipe, and a water tank installation. Spring formations do not follow fixed patterns and many types of construction are employed to develop the supply. Experience and judgment are essential factors in the design and construction of water supplies derived from springs.

Springs are places where, without the aid of man, water flows from rock or sand onto the land or into a body of surface water.

That portion of precipitation which percolates into the ground is called ground water. Ground water may be divided into two zones - saturated and unsaturated. The surface of the saturated zone is known as the water table. Ground water in the unsaturated zone moves downward with the pull of gravity only when above field capacity, but water in the saturated zone moves horizontally and down gradient with the water table. An outcrop of the saturated zone produces a spring. Four general types of springs are shown in Figure 10.1.

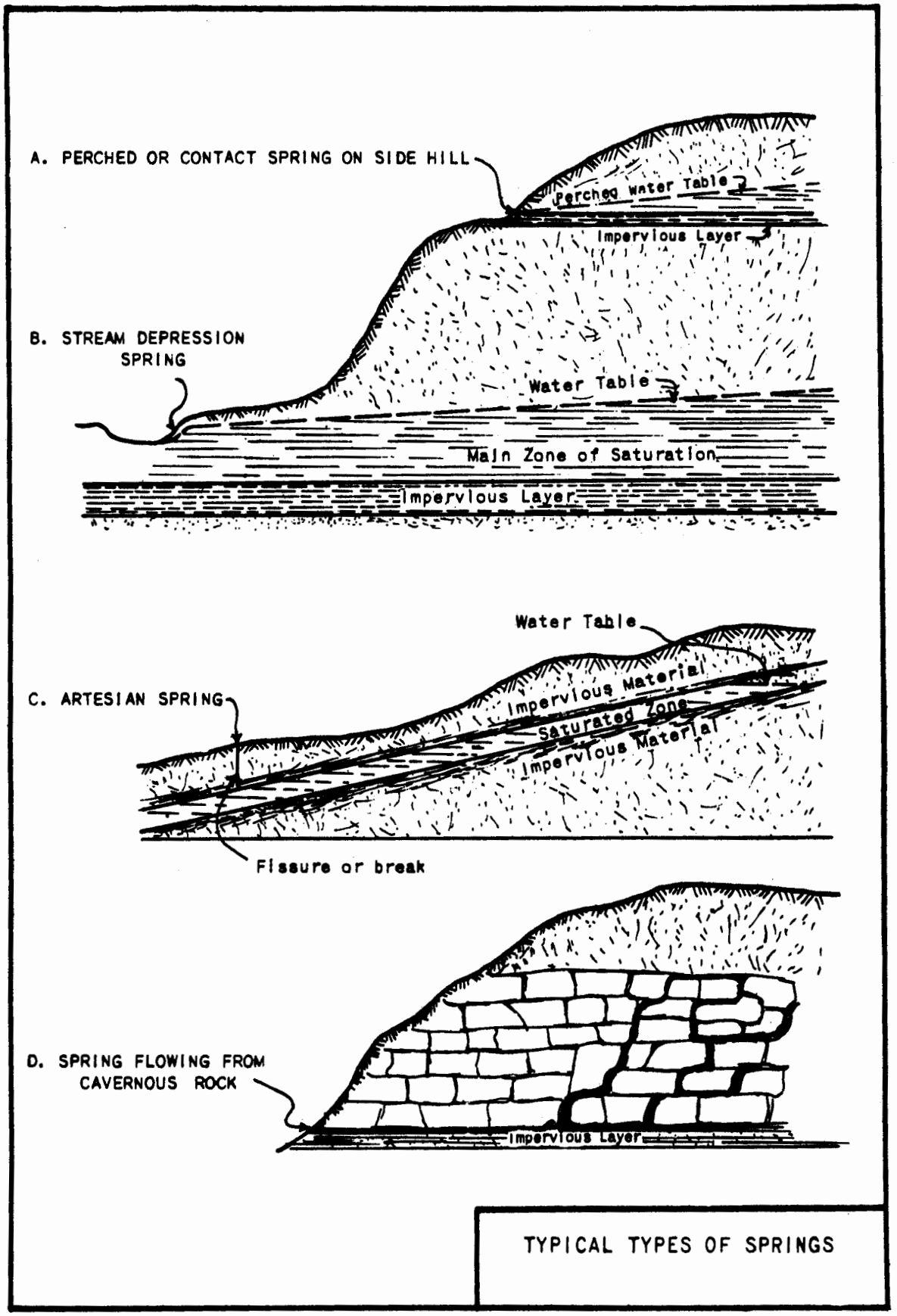
Springs similar to those shown in Figures 10.1-A and 10.1-B are usually developed by constructing a cutoff trench.

The flow of the artesian type of spring shown in Figure 10.1-C can usually be increased by removing obstructions at the mouth.

Springs that originate from a rock fissure (Figure 10.1-D) or from one central seep in the bottom of a draw are generally developed by constructing a spring box around the seep. A collection system is seldom used.

2. DEPENDABILITY

The type of spring shown in Figure 10.1-A frequently is the least dependable supply because of the limited storage that may be available. The artesian type spring shown in Figure 10.1-C usually affords the most dependable supply; however, this does not always hold true. The dependability of springs is difficult to estimate because of the many variables that affect the source of supply. The type of spring, conditions found after an exploratory excavation, and local information as to the past behavior of the spring, are all factors that should be considered. Sound judgment must be used to eliminate the expensive development of springs that may soon go dry. Where possible, the flow of springs should be measured to determine how nearly it will meet stock water or other requirements.



TYPICAL TYPES OF SPRINGS

Figure 10.1

3. COLLECTION

In the development of a spring it is often necessary to provide a means of picking up or collecting water from several outcrops and leading it to one central point of concentration to provide an adequate supply. This is especially true in developing hillside springs. The collection trench or gallery is usually dug just above the line of seepage and excavated to a depth that will intercept the water-bearing strata. In some cases, it may be necessary to follow the sand veins into the bank a short distance to remove any obstructions so a sufficient flow is obtained. The trench usually is excavated to a width of about 2 feet to receive the collectors, and for ease of digging.

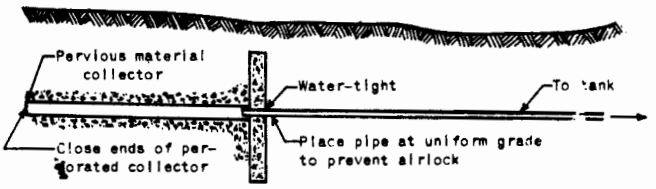
The collector may consist of clay tile or perforated pipe laid in graded gravel and sand or be simply a trench filled with graded gravel and sand. In the construction of the collector it is good practice to tamp impervious clay in the downstream side of the trench, as illustrated in the "Detail of Collector" in Figure 10.2. The clay core is tied in with the impervious material below to intercept the water and cause it to flow laterally to the point of collection. Under some conditions, sand points may be driven into the saturated vein to serve as collectors.

The head wall or cutoff usually is constructed in the shape of a large V with the apex at the lower side and the wall extending back into the banks to prevent the water from going around the ends. This detail is illustrated in Figure 10.2. The wall should be at least 6 inches thick if concrete is used, and should be carried deep enough to prevent underflow. Rubble masonry, clay, or other impervious materials may also be used. Rock and graded gravel should be placed above the head wall to collect any silt that may be deposited and to direct the flow into the outlet pipe.

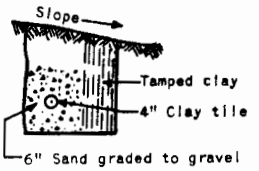
A spring box may be incorporated in the apex of the V-shaped wall. It has the advantage of making the spring more accessible, permitting maintenance without disturbing the system as a whole.

4. SPRING BOXES

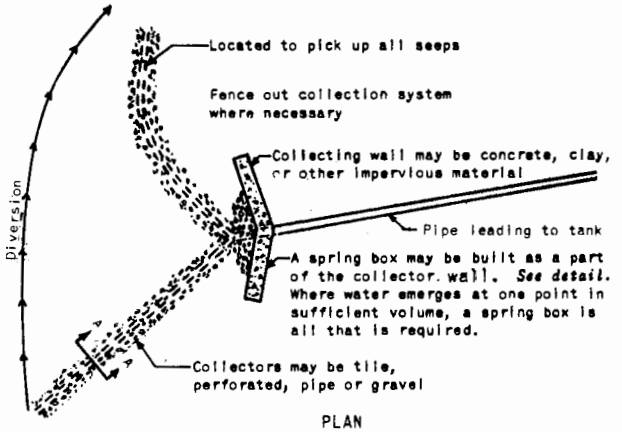
In the event that a spring box is used with a collection system, the upper wall should have openings or be constructed of some porous material so that all the water collected by the galleries can enter the box. Spring boxes for springs not requiring a collection system may or may not have a porous upper wall, depending upon the spring. In the case of springs coming out of a rock ledge, the sides of the spring box frequently are tied into the rock wall which serves as the upper side of the box.



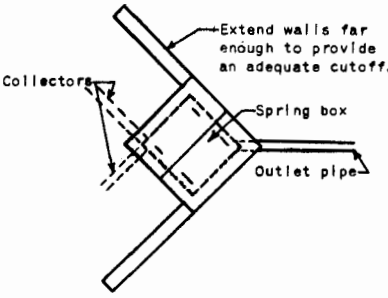
SECTIONAL ELEVATION OF COLLECTION SYSTEM



DETAIL OF COLLECTOR
Section AA

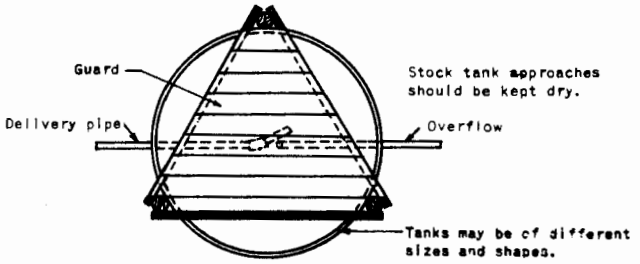

Located to pick up all seeps
Fence out collection system where necessary
Collecting wall may be concrete, clay, or other impervious material
Pipe leading to tank
A spring box may be built as a part of the collector wall. See detail. Where water emerges at one point in sufficient volume, a spring box is all that is required.
Collectors may be tile, perforated, pipe or gravel
Diversion

PLAN

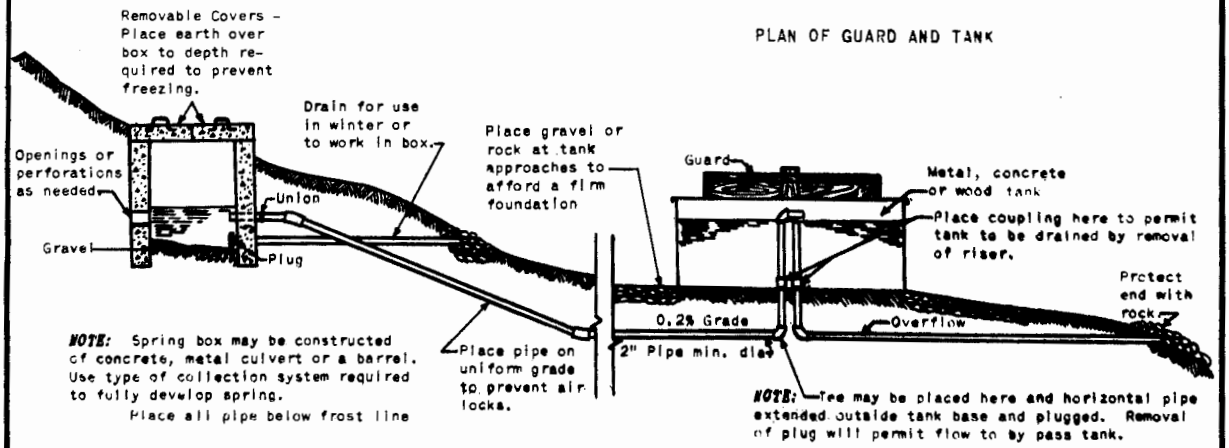


PLAN OF SPRING BOX USED WITH COLLECTION SYSTEM

COLLECTION SYSTEM



PLAN OF GUARD AND TANK


Removable Covers - Place earth over box to depth required to prevent freezing.
Drain for use in winter or to work in box.
Openings or perforations as needed
Union
Gravel
Plug
Place gravel or rock at tank approaches to afford a firm foundation
Guard
Metal, concrete or wood tank
Place coupling here to permit tank to be drained by removal of riser.
Protect end with rock
0.2% Grade
Overflow
2" Pipe min. dia.
NOTE: Spring box may be constructed of concrete, metal culvert or a barrel. Use type of collection system required to fully develop spring.
Place all pipe below frost line
Place pipe on uniform grade to prevent air locks.
NOTE: Tee may be placed here and horizontal pipe extended outside tank base and plugged. Removal of plug will permit flow to by pass tank.

SECTIONAL ELEVATION
SPRING BOX AND WATER TANK

Figure 10.2

SAMPLE SPRING DEVELOPMENT

4. SPRING BOXES (CONT'D)

Spring boxes may be constructed of monolithic or precast concrete. Metal culvert sections or oil barrels may be used, also. Generally, wooden spring boxes are not recommended as their life is short. All spring boxes must be covered with a tight-fitting top to prevent any dirt or debris from getting inside. In case the spring is used for domestic water supply, the cover must be water-tight and the spring protected against any possible source of contamination. In cold weather the spring box and appurtenances should be covered with earth to a depth that will prevent freezing.

5. DELIVERY AND OVERFLOW PIPES

An important part of the spring development is the arrangement of the delivery and overflow pipe layout. Experience indicates that a minimum pipe diameter of $1\frac{1}{4}$-inch should be used where the grade is over 1 percent. Where the grade is between 0.5 percent and 1 percent, a $1\frac{1}{2}$-inch minimum is recommended. Grades under 0.5 percent require a 2-inch minimum pipe. Grades less than 0.2 percent are not recommended. When pipe sizes smaller than those recommended are used there is a tendency for them to become clogged with foreign matter, and they are difficult to clean.

The delivery pipe should be laid carefully on a continuous, uniform grade. Sags or high spots usually create air-locks which may stop the flow, they also reduce the velocity of the flow. Pipes should be laid below the frost line and covered to prevent freezing.

The inlet to the delivery pipe should be placed at least 6 inches above the floor of the spring box to provide a silt trap. A water-tight connection must be made where the pipe leaves the spring box or goes through a cutoff wall. A union should be placed on the pipe outside of the wall to permit easy removal of pipe sections.

Wherever possible, the outlet pipe should be placed at such an elevation that a head of water is not created on the spring. An increase in head will result in a corresponding decrease in the rate of flow, and in the case of a weak spring, may cause the seeps to change their path of flow.

The pipe connection with the water tank may be accomplished in a number of ways. The practice of bringing the pipe under the tank and vertically through the bottom is usually considered the most desirable where the tank is to be used during freezing weather. It also has been found beneficial to have the inlet and outlet pipes fairly close together near the center of the tank. Even though the water freezes around the edge of the tank it will tend to stay open at the center. Figure 10.2 illustrates a good method of bringing the delivery pipe into the tank, as well as a method of by-passing the flow underneath the tank.

6. PROTECTION

Springs frequently occur at points which are susceptible to flooding during periods of high runoff. Protection should be given to the spring and its appurtenant structures to permit its use without continuous maintenance. Properly located diversions will afford protection in many instances. The spring itself may be developed so that flood flows passing over the top will not cause damage. The tank should be set above the floodwater level at a protected point by using a long delivery pipe placed at proper grade.

HYDRAULIC RAMS

1. GENERAL

A hydraulic ram is a pump operated by water power. It utilizes the power developed by a given quantity of falling water to force a much lesser amount to an elevation above the source of supply.

Water is conducted to the ram through a drive pipe which operates under a given head, depending on the differences in elevation between the source of supply and the ram. The water entering the ram is under pressure and is allowed to escape through a valve until a certain velocity is reached that causes the escape valve to close quickly, building up pressure which opens a flap valve, forcing a small portion of the water into the air chamber which connects directly with the delivery pipe. As soon as the pressure equalizes, the flap valve leading to the air chamber closes, the escape valve opens and water again flows out the escape valve until the velocity is built up to close it, repeating the process. Each stroke of the ram forces a certain amount of water out through the delivery pipe. The pulsations occur from 25 to 100 times a minute, so the resulting discharge is nearly continuous.

The volume of water that a ram will pump is dependent on the fall between the source of supply and the ram, the height the water is to be raised from the ram to the outlet, and the quantity of water available.

Manufacturers build rams that will operate successfully on flows of $1\frac{1}{2}$ gpm or more when operating under a head of not less than 2.0 feet. The approximate pumping capacity of hydraulic rams for various ratios of height to which water is to be raised to the fall is given in Figure 10.3 for flows varying from 1 to 14 gallons per minute.

Flow Source to Ram in Gallons Per Minute	APPROXIMATE CAPACITY OF HYDRAULIC RAMS DISCHARGE FROM RAM TO STORAGE IN GALLONS PER HOUR Ratio: Height Water Must Be Raised/Fall From Source To Ram																
	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	8.0	6.0	5.0	4.0	3.5	2.8	2.4	2.0	1.7	1.4	1.2	1.0	0.8	0.7	0.6	0.4	0.4
2	17.0	13.0	10.0	8.0	7.0	5.7	4.8	4.0	3.4	2.9	2.4	2.1	1.7	1.4	1.2	0.9	0.8
3	25.0	19.0	15.0	12.0	10.0	8.5	7.2	6.0	5.1	4.3	3.6	3.1	2.6	2.1	1.8	1.4	1.2
4	34.0	26.0	20.0	16.0	14.0	11.5	9.6	8.0	6.8	5.8	4.8	4.2	3.5	2.9	2.4	1.9	1.6
5	42.0	32.0	25.0	21.0	18.0	14.4	12.0	10.0	8.5	7.3	6.0	5.2	4.4	3.6	3.0	2.4	2.0
6	51.0	39.0	30.0	25.0	21.0	17.4	14.4	12.0	10.2	8.7	7.2	6.3	5.2	4.3	3.6	2.8	2.4
7	59.0	45.0	36.0	29.0	25.0	20.0	16.8	14.0	11.9	10.2	8.4	7.3	6.1	5.1	4.2	3.3	2.8
8	68.0	52.0	41.0	33.0	28.0	23.0	19.0	16.0	13.6	11.6	9.6	8.4	7.0	5.8	4.8	3.8	3.2
9	76.0	58.0	46.0	37.0	32.0	26.0	21.5	18.0	15.3	13.1	10.8	9.4	7.9	6.5	5.4	4.3	3.6
10	85.0	66.0	51.0	42.0	36.0	28.0	24.0	20.0	17.0	14.6	12.0	10.5	8.8	7.3	6.0	4.8	4.0
11	94.0	72.0	56.0	46.0	39.0	31.0	26.0	22.0	18.7	16.0	13.2	11.5	9.7	8.0	6.6	5.3	4.4
12	102.0	79.0	62.0	50.0	43.0	34.0	28.0	24.0	20.4	17.5	14.4	12.6	10.5	8.7	7.2	5.7	4.8
13	111.0	85.0	67.0	54.0	46.0	37.0	31.0	26.0	22.1	18.9	15.6	13.6	11.4	9.5	7.8	6.2	5.2
14	119.0	92.0	72.0	58.0	50.0	40.0	33.0	28.0	23.8	20.4	16.8	14.7	12.3	10.2	8.4	6.7	5.6
15	128.0	98.0	77.0	63.0	53.0	44.0	35.0	30.0	25.5	21.9	18.0	15.8	13.2	10.9	9.0	7.2	6.0

Figure 10.3

1. GENERAL (CONT'D)

In order to ascertain the practicability of installing a ram under any particular set of conditions, the information shown following Figure 10.4 should be collected. Submission of this information to reputable ram manufacturers will enable a recommendation to be made regarding the installation. Due to the variations encountered in ram installations and the difference in standards embodied in the rams built by various manufacturers, no attempt is made to discuss the details of selection and installation.

DIAGRAMMATIC SKETCH OF RAM INSTALLATION

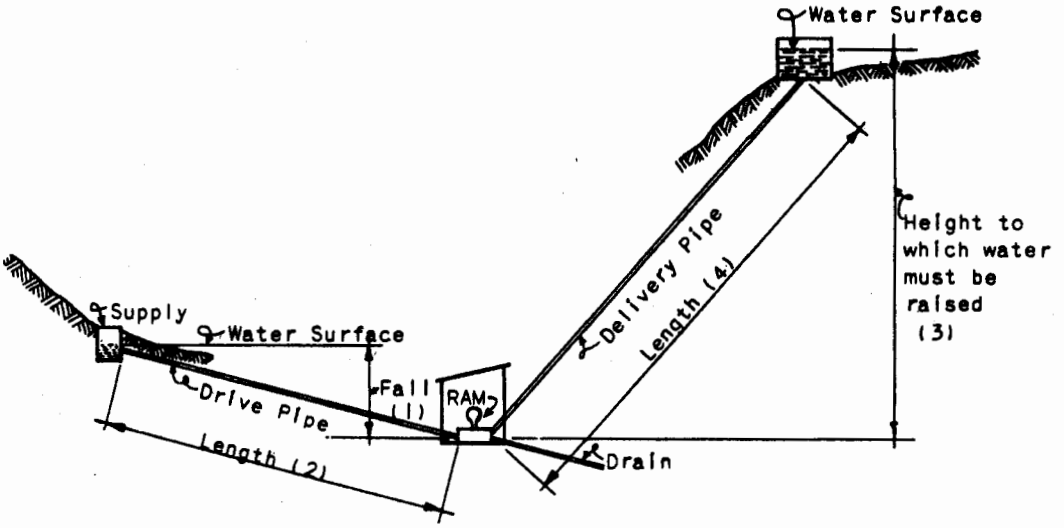


Figure 10.4

The following determinations should be made in considering a hydraulic ram installation:

1. Fall in feet from the source of supply to the site of the ram.
2. Length of pipe required to conduct the water from the source of supply to the ram.
3. Height in feet the water is to be raised - vertical distance between ram and point of delivery.
4. Length of pipe required to conduct the water from the ram to the point of delivery.
5. Supply of water available to ram in gpm. Wherever possible, the flow should be measured through a weir or by catching it in a container. Use the flow occurring during the dry season.
6. Volume of water required in gallons per day and the purpose for which it is to be used.

CONTENTS

PART 11

WELLS AND PUMPS

Subject	Page
1. General	11-1
2. Irrigation Wells and Pumps	11-1
Well Site-	11-1
Test Holes and Logs-	11-2
Types of Construction-	11-2
Construction Methods	11-4
Sand Bucket or "Standard" Method-	11-4
Hydraulic-Rotary Method	11-5
Reverse Hydraulic-Rotary Method	11-6
Well Screens	11-6
Well Casing-	11-8
Development-	11-9
Well Testing	11-10
Pumping Plant-	11-12
Selection of Pump	11-12
Centrifugal Pump-	11-14
Turbine Pump-	11-16
Drive Mechanisms-	11-22
Pumping Head-	11-25
Drawdown-	11-25
Power Requirements-	11-26
Power Units	11-28
Cost of Pumping	11-31
Factors Relating to Design of System	11-37
Outlet Protection-	11-39
Battery Installation	11-39
3. Domestic Wells and Pumps	11-39
Types of Wells	11-39
Well Location-	11-43
Equipment of Well-	11-43
Casing-	11-43
Drop Pipe	11-44
Cylinder-	11-44
Pump Rod-	11-47
Power Requirements-	11-47
Windmill-	11-47
Tower	11-47

LIST OF FIGURES

PART 11

WELLS AND PUMPS

Figure Number	Title	Page
11.1	Thickness for Diameter of Well Casing	11-8
11.2	Head Capacity Curve for Well	11-11
11.3	Capacity and Horsepower Required for Centrifugal Pumps	11-14
11.4	Diagram of Centrifugal Pump System	11-15
11.5	Characteristic Curves for Turbine Pump	11-17
11.6	Characteristic Curves for Turbine Pump	11-19
11.7	Turbine Pump with Submersible Motor	11-20
11.8	Direct Connected Motor Driven Turbine Pump	11-23
11.9	90° Gear Head Drive	11-23
11.10	Flat and V-Belt Drives	11-24
11.11	Head Losses in Turbine Pump	11-27
11.12	Piston Speed in Feet Per Minute at Various RPM	11-30
11.13	Performance Standards for New Deep-Well Pumping Plants	11-32
11.14	Maximum Fuel Requirements for a Good Pumping Plant	11-32
11.15	Relationship Between Discharge Pressure and Lift	11-33
11.16	Pump Outlet and Division Box	11-40
11.17	Typical 3 Well Battery Installation	11-41
11.18	Typical 4 Well Battery Installation	11-42
11.19	Weights and Dimensions of Casing	11-45
11.20	Light Weight Galvanized Casing	11-45
11.21	Cylinder Size for Various Casings	11-46
11.22	Size of Cylinder - Type of Pump - Depths	11-46
11.23	Sizes of Wood Pump Rods	11-46
11.24	Capacity of Cylinders and Power Required for Different Heads	11-48
11.25	Pumping Capacity of Mills	11-49

PART 11

WELLS & PUMPS

1. GENERAL

Technicians of the Soil Conservation Service, depending upon their locality, may or may not be requested to give assistance in the construction, development and testing of irrigation and domestic wells and the installation of pumps from these facilities. The following has been prepared to aid in the understanding of the principles and techniques involved where such planning is needed.

2. IRRIGATION WELLS AND PUMPS

Well Site

In locating a well site, first select an area where indications point toward an adequate water supply. The United States Geological Survey and state organizations have a large amount of information on existing ground waters and should be consulted in the selection of well sites whenever conditions are unknown.

Existing wells should be considered to avoid interference by overlapping the zones of influence.

The well should be located in close proximity to the area to be irrigated to reduce transmission losses. It is generally recommended that the well be located at the high point of the irrigable land so that flow to all parts can be obtained by gravity, thus obviating costly and troublesome elevated ditches or expensive installation of pipes or flumes. Where a closed distribution system, such as in a sprinkler system, is used, the location may be better near the center of the area to be irrigated. This location can reduce the cost of main lines. Where the high point in the field is relatively a small area, it might be better to force water up to it than to draw water for the whole field the extra few feet. This may save some drop structures as well. A survey should be made of the area proposed for irrigation and the well site to determine the high point. The extent and type of survey will depend on the topography and slope of the land. Generally speaking, a study of the field along with a few random shots will indicate the high point. Fields having a low gradient and fields of undulating topography may require a topographic survey to make this determination.

In many cases, test wells indicate conditions are not favorable for obtaining a satisfactory well at the most desirable point on the area under consideration. It is then necessary to spot the next best location and proceed with more test wells.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Test Holes and Logs

The construction of an irrigation well is an expensive item, making up approximately one-half of the total cost of a pump installation. It is important, therefore, to make studies to assure an adequate water supply exists before construction is started. It is difficult to make a complete geological analysis as practically all of the water-bearing formations in this region are alluvial and thus may not follow a regular pattern. A study of existing wells will give valuable information. The United States Geological Survey has ground water reports which are available for many areas.

A test hole at the exact site of the proposed irrigation well will give the best information concerning the availability of water-bearing sand and gravel. Test holes vary in size with localities but usually range from 4 to 6 inches in diameter. An accurate log should be gathered from the test hole, showing the size of the hole, the method used in putting the hole down, the depth at which each formation was encountered, the thickness, the geological name (if any), color and description of each different material, including a sieve analysis of those formations classed as aquifers. A sieve analysis is particularly important in medium to fine formations or larger graded formations if artificial gravel packing is contemplated. The log should show the depth to static water, measured after the water level has stabilized. The log having the best gradation of particles within the water-bearing formation in relation to depth of saturation, etc., will indicate the most desired location for the well from the standpoint of yield. Individuals familiar with conditions in the area can make a reliable estimate of the probable yield from a study of the log of the well and the geology of the area. For example, a water-bearing formation may yield 20 gallons per foot of drawdown in one area and as much as 100 gallons in another area. Test holes drilled prior to well construction will save many dollars of expense in practically every instance. This is particularly true in any shallow well area, as such wells usually derive their water from subsurface strata that cannot be well defined from surface investigations.

Types of Construction

There are two general types of well construction; one is used for the development of a well in the natural formation, the other is used for the development of a well through the use of a gravel treatment (gravel pack). The type used should be dependent upon an analysis of the water-bearing formation.

In the construction of a well to be developed from the natural formation, the hole is drilled just enough larger than the screen and casing to allow their insertion into the well. The hole usually is sunk with a sand bucket, bailer, or some type of reamer or undercutting tool that will allow placement of the screen and casing to be concurrent with drilling. However, if rotary-hydraulic equipment is used, the screen and casing are set after the hole is completed.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Types of Construction (cont'd)

The construction of a well to be gravel-packed is different in that some provision must be made for placement of a gravel envelope around the screen. Several methods have been employed to accomplish this but probably the one most extensively used, particularly in this region, is the practice of drilling the hole at a diameter twelve or more inches greater than the diameter of the screen, placing the screen and casing, and then filling the area between the screen and the wall of the hole with a gravel treatment. Rotary-hydraulic equipment is popular for this type of construction.

The composition of the water-bearing formation may be such that the method of construction is apparent simply from observation. For the purpose of a guide, however, E. W. Bennison, editor of "Johnson National Drillers' Journal", and author of "Ground Water, Its Development, Use and Conservation", suggests the following:

> "Generally speaking, we would say formations whose effective size (Hazen) is more than 0.010" and whose uniformity coefficient was more than 2.0 do not require treatment (although proper treatment would not be harmful)".

From studies which have been made at Colorado A & M College and other locations, the following conclusions have been made:

(1) The filter should have a minimum thickness of 3 inches and a maximum of 12 inches.

(2) The gravel pack should be selected so that the filter pack - aquifer ratio (ratio of average or 50% sizes) is between 5 and 8. The lower limit is 5 in order to minimize the head losses and the upper limit, 8, to prevent excessive sand movement.

(3) The uniformity coefficient of the gravel should not exceed 2.0.

The effective size of a formation is the grain size at which 10% of the particles are finer and 90% are coarser than the effective size. Uniformity coefficient is the ratio of the diameter of a particle that has 40%, by weight, of the sample coarser than itself to the diameter of a particle that has 90%, by weight, of the sample coarser than itself.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Types of Construction (cont'd)

Ordinary grade sizes are:

	Inches	Millimeters
Coarse gravel - average diameter	0.1875 and up	4.75 and up
Medium gravel - average diameter	0.080 - 0.1875	2.00 - 4.75
Fine gravel - average diameter	0.040 - 0.080	1.00 - 2.00
Coarse sand - average diameter	0.020 - 0.040	0.50 - 1.00
Medium sand - average diameter	0.010 - 0.020	0.25 - 0.50
Fine sand - average diameter	0.004 - 0.010	0.10 - 0.25
Very fine sand- average diameter	0.002 - 0.004	0.05 - 0.10
Silt, clay - average diameter	Up to - 0.002	Up to- 0.05

For the natural development of a well, a screen is used with a slot opening of a size that will let all the fine particles possible enter the well without causing settling of the formation around it. In some formations, it is possible to remove as much as 80%, by weight, of the particles next to the screen.

In the development of a gravel-packed well, the grading of the gravel treatment is a function of the effective size of the natural formation. If the effective size of the gravel treatment is too large it may not bridge, and if it is too small it may even be detrimental to the point of decreasing the yield of the well. The relationship between the size of particles in the gravel treatment and those in the natural formation is expressed in terms of the uniformity coefficient, keeping that of the gravel treatment at 2.0 (or slightly less) times that of the natural formation. Selection of a screen for a gravel-packed well is dependent, therefore, upon the size of particles in the gravel treatment which, in turn, is dependent upon the size of particles in the natural formation. For this type of well a screen is used with a slot opening of a size that will keep out 85% to 90% of the gravel treatment.

Certain states have developed and published minimum standards for artificially gravel-packed irrigation wells.

Construction Methods

The three methods of constructing irrigation wells most commonly used in this region are the sand bucket method, the hydraulic-rotary method, and the reverse hydraulic-rotary method. Other methods will not be discussed in this handbook. A discussion of approved methods of well construction is contained in United States Department of Agriculture Circular No. 546, entitled "Putting Down and Developing Wells for Irrigation".

Sand Bucket or "Standard" Method. When the water-bearing formations are at a shallow depth and are not covered by a deep layer of consolidated material or interspersed by layers of clay, boulders, or rocks, the use of some type of bailer is an effective method of putting down irrigation wells. This method is not generally adapted to wells exceeding a depth of 80 feet.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Construction Methods (cont'd)

Sand Bucket or "Standard" Method (cont'd)

When this method is used, an open pit is dug by hand or bored with an earth auger down to the water level or to sand, in case it is encountered before the water table is reached. A blind casing is then installed and the well is put down by removing the material from the hole by means of a bailer operated by a portable well drilling rig, an engine-driven hoist, and derrick. The blind casing is driven at the same rate the excavation proceeds. Since it is very difficult to pull casing for more than 20 feet, the well driller starts with a larger casing and goes down 20 feet or so and then starts out with a new string of casing inside the first for another 20 feet. This process is continued until the desired depth is reached. The casing is forced down by levers or by weights placed in special boxes hung around the casing. The well casing then is placed in the center of the well.

If the well is to be gravel packed, the selected material is shoveled into the space between the blind casing and the well casing. As the gravel pack is placed, the blind casing is gradually lifted and removed from the well. At no time does the well driller lift the blind casing higher than the aggregate that is being placed in the well.

Hydraulic-Rotary Method. The hydraulic-rotary method is adapted to drilling both deep and shallow irrigation wells. It is an effective method where layers of clay are encountered, which frequently cause considerable delay when using a bailer. This method is one of the fastest used in drilling wells. Wells drilled by this process are put down by means of a rotating bit through which a mixture of clay and water is forced at high pressure. The bit is attached to a hollow drill stem through which the clay and water mixture is pumped. The material in the hole is loosened by the rotation of the bit, and the loosened material is carried to the surface by the upward flow of water and clay. Some of the clay in the mixture is deposited on the side of the hole, and the constant rubbing of the drill bit forms a substantial clay lining. No casing is used ordinarily while drilling the hole, the clay lining forming a wall sufficiently strong to keep the walls from caving. Wells of several hundred feet may be drilled by this method. The drills used in this method vary with the well drillers, each having his preference.

The shank is hollow and has an orifice on each side from which water emerges under pressure. The bit is attached to a drill stem consisting of a heavy pipe which is turned by means of a rotating table through which the drill stem can slide as the hole deepens. The drill stem is connected by a hose to a pressure pump which forces the mixture of mud and water into the drill stem and down to the bottom of the well where it picks up loosened materials and rises to the surface. The mixture of clay, water and drillings are run into a sump through a channel long enough to permit the sand and chips in the drillings to be deposited before they reach the sump. From the sump the mixture of clay and water is taken into the force pump again to be forced into the drill stem and to the bottom of the well to

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Construction Methods (cont'd)

Hydraulic-Rotary Method (cont'd)

pick up more loosened materials. This process is continued until the hole is drilled to the desired depth. The drill is then withdrawn and the casing, including the screen, is lowered into the hole and centered. The space between the casing and the wall of the well is then filled with the gravel-pack. As soon as possible after the well is completed, it should be developed in order to remove any clay remaining in the gravel or sand before it has a chance to settle and seal the pores in the materials surrounding the perforated casing.

Reverse Hydraulic-Rotary Method. The reverse hydraulic-rotary method differs from the hydraulic-rotary method previously described in that the material loosened by the bit is removed from the well through the drill stem. The drill stem is made of large-diameter pipe and is connected to the suction inlet of a horizontal centrifugal pump by means of a swivel and hose. The water, with its load of material from the bottom of the well, is discharged into a pit. After it has deposited its load in this pit, the water is run back into the well. The well is kept filled with water to reduce the suction lift and to keep the sides of the hole from caving. Clay is sometimes added to the water to strengthen the sides. The equipment for rotating the bit is similar to that used in hydraulic-rotary rigs. This method is most effective in sandy formations not containing large rocks which might clog the pump. If a large rock is encountered which cannot be forced aside or carried upward by the velocity of the water in the drill stem, it must be removed by an orange-peel or similar type of bucket. Layers of clay are penetrated without difficulty. Wells 50 inches in diameter and over 200 feet deep can be drilled by this method. Some rigs, through the additional use of compressed air, are equipped to drill wells to depths as great as 500 feet. No casing is used. Because of the danger of caving, drilling is carried on continuously after it is started. One or two days usually is enough to drill a well unless unforeseen difficulties are encountered.

As soon as the drilling is completed, the casing is set in the hole and the gravel placed in the same manner as described before.

Well Screens

The most efficient type of screen is one made up of rings that are cone-shaped in cross section with the base of the cone to the outside and held in place by vertical members inside the screen. This gives a continuous slot entrance for the full circumference of the screen and provides for the maximum total entrance area and the least friction. The width of the slot opening is controlled by the spacing of the rings. Openings are measured in thousandths of an inch in width with standard openings equal to sand and gravel grade sizes shown in the previous table. This type of screen is patented and generally is considered expensive for irrigation wells. Although high in first cost, under certain conditions this type of screen may be very economical in the long run because of reduced operating costs.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Well Screens (cont'd)

Any type of flat hole, regardless of shape, offers the greatest possibility of clogging, therefore, a screen made up by perforating casing (sheet metal) is not desirable unless the perforations are of the chisel type. Chisel type perforations may be of several forms but all provide for a slot with minimum width of opening to the outside in an effort to reduce clogging. The only limitation to this type of screen is the size and spacing of the opening. Slots too wide, too long, too closely spaced, or improperly made, may weaken the casing to the point where it will collapse, particularly if the well is surged to the point necessary for proper development. Certain manufacturers emboss the perforated opening for added strength and guarantee their product to be stronger than it was prior to perforation. In requesting a screen of this type, it should be specified that the screen have a strength equal to that of the other casing used in the well. (See Figure 11.1.) The spacing, length and width of perforated openings are given in inches and fractions of an inch.

Perforated casing sometimes is covered with fine screen for use in irrigation wells constructed in fine sand. The casing is perforated by drilling 5/8-inch diameter holes which are covered with a 12- or 14-mesh brass screen. The brass screen is protected by a sheath of 1/4-inch mesh galvanized iron hardware cloth. This type of casing is expensive but it is effective in keeping out fine sand.

Another type of casing sometimes used consists of plain or reinforced concrete rings. The rings are connected by tongue-and-groove joints or have vertical holes through which rods or cables are strung to hold the casing together. Tie plates, extended across the joints and bolted to the adjoining sections, are sometimes used to hold the sections together. The thickness of the walls of the rings is from 2 to 3 inches. Concrete casing and wall screen should meet the standards set up in ASTM Designation C76-56. The perforations in concrete casing are in the form of slots cast in the rings by inserting wood or metal wedges which are subsequently removed. The slots are placed vertically or horizontally and are tapered toward the outside of the casing. Perforated concrete casings may be used when they provide an adequate percentage of open area and the slot size is in proper relation to the particle size of the filter material.

From studies made at Colorado A & M College and elsewhere, the following conclusions have been made on screens:

(1) The well screen should have a slot size so that at least 15% of the filter material is larger than the opening.

(2) The screen should have at least 15% to 20% of open area if head losses are to be held to a minimum.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Well Screens (cont'd)

The length of perforated casing used in the well will depend upon the thickness and location of the water-bearing sand and gravel. Blank casing can be installed between perforated sections when it is known that there is a non-producing layer between two layers of gravel or sand. The perforated casing should not extend above the water level in the well when pumping at the rated capacity.

Unless the bottom of the well is on bedrock, the bottom of the casing should be plugged with steel or concrete. Many drillers weld a plate on the end of the casing before lowering it in the well. Other drillers pour a concrete plug after the casing is in place. The well casing should be placed in the center of the drilled hole so that the gravel pack is uniform in thickness around the casing. Some drillers weld light bars on three sides of the casing so proper spacing is simplified. Spacers of some kind are essential.

Well Casing

Several different types of casings are used in irrigation wells. Of these, the bolted casing composed of rolled sheets of either black or galvanized iron is in common use. The vertical joints in the sections are lap-riveted or butt-welded. The sections are usually made in 2- to 12-foot lengths and of any standard diameter up to 48 inches. The thickness of the material depends on depth of the well and the diameter of the casing. The table below shows minimum gages recommended.

Depth of Well	THICKNESS FOR DIAMETER OF WELL CASING OF:				
	14-Inch	16-Inch	18-Inch	20-Inch	24-Inch
20	16 gage	16 gage	16 gage	14 gage	14 gage
40	16 gage	14 gage	14 gage	14 gage	14 gage
60	14 gage	14 gage	14 gage	14 gage	12 gage
80	14 gage	14 gage	12 gage	12 gage	10 gage
100	14 gage	12 gage	12 gage	10 gage	10 gage
120	12 gage	12 gage	12 gage	10 gage	10 gage
140	12 gage	12 gage	10 gage	10 gage	8 gage
160	12 gage	10 gage	10 gage	8 gage	8 gage
180	10 gage	10 gage	10 gage	8 gage	8 gage
200	10 gage	10 gage	8 gage	8 gage	8 gage
500	8 gage	8 gage	8 gage	8 gage	8 gage

This type of casing is comparatively cheap and is easy to install. Galvanized and asphalt-coated casing will last longer than black casing. In certain localities where soil or the water contains corrosive elements, asphalt-treated casing will outlast the galvanized casing.

Figure 11.1

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Development

The actual development of a well from a natural formation is the same as for a well that is gravel-packed except that in the latter it is necessary to provide for the addition of the gravel treatment during development. The purpose of development is to increase and enlarge the voids around and out from the well screen which, in turn, will decrease the friction to water flow through the formation, lower the hydraulic gradient and decrease the subsequent drawdown. This is accomplished by the removal of fine particles from the formation. Development is a very important step in construction of a well and should be carefully and positively done.

Development by the use of surge plungers is the most violent method used, and if properly handled will give the most complete job and will improve almost any well. The plunger is made in the form of a wooden cylinder only slightly smaller than the inside diameter of the well casing and attached to a drill stem or length of pipe to provide weight. It is operated up and down inside the casing and acts in the manner of a pump piston. The longest stroke possible is used, keeping the plunger well submerged at the top of the stroke, and allowing it to lower to the top of the screen at the bottom of the stroke. The weight of the plunger and stem provides energy for the downward movement and it is raised by power from the drill rig. The downstroke of the plunger forces water from the well into the formation and has a tendency to free or loosen up fine particles which are then pulled into the well by the water coming in on the upstroke. It is necessary to periodically clean the well of sand during surging operations in order to obtain the maximum effect throughout the length of the screen. The necessity for mild action at the beginning of surging cannot be over-emphasized. Violent action at this stage will cause the particles of the formation to bridge across in such a manner that they may become wedged or "locked" so tightly that the flow into the formation from the well on the downstroke will not free them. When this happens, they block the movement of particles toward and into the well and further development is useless. Such action may actually be injurious rather than beneficial to the development. It probably is because of a lack of understanding of this that some drillers have failed to attain proper development by the surge method which caused them to be opposed to it. As stated before, proper surging, beginning with mild action increasing in violence only as the amount of sand entering the casing decreases, will help almost any well. In fact, in some small diameter wells surging has been known to increase yields as much as 300 percent.

Another, and probably the most common method of development used in this state, is known as "backwashing" or "rawhiding". This is a method of pumping; the pump being started slowly and gradually brought up to the maximum yield of the well, then stopped, allowing the water in the pump column to rush back into the well and then into the formation. The process is repeated until no more sand comes into the well while being pumped.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Development (cont'd)

The method causes a maximum difference in pressure head and results in what might be compared to rather mild surging. There are several variations of this method, differing only as to when the pump is started or stopped. As an example, some drillers, after gradually bringing the pumping up to the maximum yield of the well and stopping as explained above, start the pump again but shut it off as soon as water reaches the discharge, repeating on this basis which will give them less difference in head and consequently less violent action at the well end. It should be noted that pumping always starts slow and is gradually increased to the maximum. This is because sudden hard pumping might cause the pump to become locked by the sudden influx of sand.

The driller should always be required to furnish the pump for this type of development as there is an excessive amount of wear on it due to sand in the water. Use of a new pump with the intent of delivering it to the farmer as part of the installation would be the same, in effect, as delivering a pump already having several years wear. Further, the chance of the new pump being one that properly fitted the requirements would be very small.

Some of the most common faults in well construction are: failure to analyze the formation to determine the proper type of construction; lack of attention to gradation of the gravel treatment if the well is to be gravel-packed; improper placement of the gravel pack so that a layering effect of coarse and fine material results; improper type and size of screen opening; improper centering of the screen so that it is in contact with the foundation at some point; and use of the wrong method of development. Each of the above are seldom, if ever, overlooked by any one driller but failure to consider any one of them may materially reduce the yield of the well.

The importance of proper construction and development may be illustrated by the fact that a reduction of five feet in drawdown for a well producing 200 acre feet per year will, over its estimated life period, save several thousands of dollars in operating costs.

Well Testing

After the well has been developed, it is necessary to conduct a thorough test to determine the economical yield of the well, the type and size of pump and the required horse power. Yields of nearby wells can be used only for purposes of estimation and not for the final selection of a pump. If possible, the depth to water in nearby unpumped wells should be measured at frequent intervals during the test to determine interference, if any.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Well Testing (cont'd)

In many cases, the pump used for developing the well is used to make a test of the well. After development, the static water level is measured by the wetted tape method, air line, or electric sounder, depending upon the equipment available. The static water level is the normal elevation of the ground water and is measured in feet from the surface of the ground or top of casing.

The well is pumped at a maximum rate, or at a capacity equal to or greater than the maximum future needs, until the drawdown and discharge remain constant. The yield in gallons per minute and the depth to the water surface are measured under these conditions. The pumping rate is then reduced by steps and readings taken as before. From these data, a curve (Figure 11.2) is plotted showing the relationship between drawdown and yield in gallons per minute. The drawdown in feet is obtained by subtracting the elevation of the static water level from the elevation of the water level during each test that is run. The yield per foot of drawdown will equal the discharge in gallons per minute divided by the drawdown for each test point utilized.

The pump usually is designed for the maximum rate per foot of drawdown.

The discharge of the pump can be measured by a weir, Parshall measuring flume, orifice plate or other suitable device. All of these methods are described in bulletins. The orifice plate is a simple means of measuring yield as it is screwed or clamped in the end of the discharge pipe. However, unless standard plates are used for which discharge tables have been prepared, they must be calibrated with some standard measuring device.

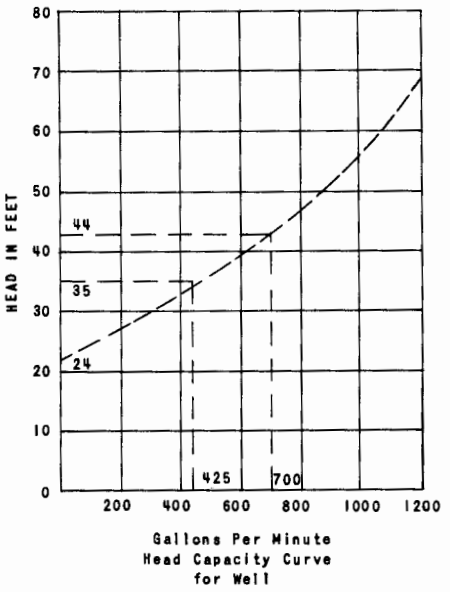


Figure 11.2

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant

Selection of Pump. The first step in the selection of a pump for a well is made after the well testing has been completed and consists of a thorough analysis of the resources of the project. The required capacity of the pump will depend upon a number of factors, the most important of which are listed below:

(1) Yield of well.

(2) The acreage suitable for irrigation from the standpoint of topography, soils, etc.

(3) The soil types, with particular attention to depth and texture as related to water-holding capacity.

(4) The crops to be grown, their root depth, rates of transpiration, etc.

(5) The possibility for diversification of crops (crops demanding water at different seasons provide for the highest total irrigable acreage).

Items 1 and 2 determine the maximum limits of development. Consideration of Items 3, 4, and 5, determine the amount of water needed per irrigation for each crop to be grown and the frequency of irrigation to be provided for. For example, in some parts of the region, corn growing under adverse weather conditions may transpire as much as 1/2 inch of water per acre per day. Under such conditions, this plant, which obtains approximately 90% of its water requirement from the first three feet of soil depth, will exhaust the readily available moisture from a silt loam soil (4 inches of water for a 3 foot depth) in eight days. Therefore, to avoid the possibility of the crop being damaged, the acreage of corn should be limited to an amount that can be covered with a 4 inch irrigation in eight days. This critical period of adverse weather condition generally occurs about the same time of year each year. Planning diversified crops that will allow for most of the water being used for the irrigation of corn during this period will allow for the largest corn acreage.

The ultimate planning is to provide for the greatest coverage in acres or crops with the smallest head of water possible commensurate with an adequate head for operation. This provides for a minimum lift requirement in the pump, the least expenditure in initial cost and, since operating cost is directly proportional to the lift, it provides for the least operation cost.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

The deep-well turbine, horizontal centrifugal, and vertical centrifugal pumps represent the three types commonly used to supply water to small irrigation systems. The deep-well turbine pump is best adapted to use in wells because it operates successfully under any head. The horizontal centrifugal pump is limited in use by the suction lift, which should not be greater than 15 feet at sea level. Vertical centrifugal pumps are not widely used, due to operating difficulties encountered in lubricating and maintaining the vertical shaft.

Horizontal centrifugal pumps usually represent the best type of installation under conditions that permit their effective operation, as the unit has the lowest first cost and is readily accessible for inspection and maintenance. Although the horizontal centrifugal pump is cheaper and has a longer life than a deep-well turbine, the latter type often is chosen for well installations even where the water level at maximum drawdown is within the limits required by a centrifugal pump, because it does not require priming nor is a pit necessary in which to install it. They may be easily connected to any type of motive power. They must be placed at a location where the suction lift does not exceed the maximum under which the pump will operate. In order to keep the suction lift within reasonable limits, it may be necessary to install the pump in a pit. Under ordinary conditions, it is not feasible to construct a water-tight pit to a depth greater than from 10 to 15 feet. Thus, the use of horizontal centrifugal pumps is limited in pumping from wells.

A vertical centrifugal pump has a horizontal impeller connected to a vertical shaft, thus the pump may be lowered to the depth required to pump water and the shaft extended to the surface where power may be applied through a one-fourth twist belt or a 90-degree gear drive. Vertical centrifugal pumps may be submerged or exposed. The exposed type is set in a water-tight sump at an elevation that will accommodate the suction lift. The shaft is extended to the surface where the motive power is applied. The main advantage of this type over the horizontal pump is that the sump can be made smaller and less inaccessible as the power is placed at the surface. It does not have much adaptation in pump irrigation installations. The submerged pump is constructed so that the impeller and suction entrance is under water at all times. It does not require priming but entails rather high maintenance costs as it is not possible to give the shaft bearings the best attention. It is set directly in the well, which is built to a large enough diameter to accommodate the pump. Pumps of this type are adapted to a maximum pumping head of about 50 feet.

Deep-well turbine pumps are similar to vertical centrifugal pumps, but have many inherent advantages. The impellers or runners are encased in shells or bowls, the number of which depends on stages required to lift the water. The vertical shaft is placed inside the discharge column

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

and provision made for proper bearing lubrication. The pump is compact and adaptable to insertion in cased wells varying in size from 8 inches in diameter up. It has the advantage over the vertical centrifugal in that the bearing and shaft arrangement is constructed to give more dependable operation, the pump is adaptable to most any reasonable pumping head, handles large volumes at high lifts, and while more costly, is constructed to give the maximum of service and efficiency over a period of years. It is especially adaptable to lifts from 50 to 250 feet. One disadvantage is that the pump must be withdrawn from the well to permit repair.

Centrifugal Pump. A centrifugal pump must be primed before it will pump. One of the simplest means of accomplishing this is to install a check valve at the bottom of the suction pipe. The pump casing and suction pipe then can be filled with water from an overhead tank by opening a hand valve. Another method commonly used in the field is to install a gate or check valve in the discharge pipe just above the pump and provide a hand pump to exhaust the air from the pump casing and the suction pipe. Exclusion of air causes water to rise and fill the suction pipe and pump. Whenever a foot valve is used on a pump, a check valve should be installed in the discharge line immediately ahead of the pump if the discharge static head is greater than 40 feet. The check valve prevents the water hammer from breaking the pump shell in the event the pump suddenly stops.

Some type of expansion sleeve should be installed in discharge lines of 50 or more feet to provide for the expansion or contraction. If cool water was to be pumped out of a creek and discharged through a pipe securely anchored on the side of a hill, the differences in temperature might cause enough contraction to break the pipe or the pump casing.

The bhp - brake horsepower - required at the shaft of a centrifugal pump under a range of heads is given in the following table:

CAPACITY AND HORSEPOWER REQUIRED FOR CENTRIFUGAL PUMPS

Size Pump	Capacity gpm	Actual hp For Pump on Lifts									
		10'	20'	30'	40'	50'	60'	70'	80'	90'	100'
2	100	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	5.4	6.0
2½	150	0.8	1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.2
3	225	1.1	2.2	3.3	4.4	5.5	6.6	7.7	8.8	9.9	11.0
3½	300	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	12.6	14.0
4	400	1.7	3.4	5.1	6.8	8.5	10.2	11.9	13.6	15.3	17.0
5	700	2.8	5.6	8.4	11.2	14.0	16.8	19.6	22.4	25.2	28.0
6	900	3.4	6.8	10.2	13.6	17.0	20.4	23.8	27.2	30.6	34.0
7	1200	4.4	8.8	13.2	17.6	22.0	26.4	30.8	35.2	39.6	44.0
8	1600	5.7	11.4	17.1	22.8	28.5	34.2	39.9	45.6	51.3	57.0

Figure 11.3

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Centrifugal Pump (cont'd)

The efficiencies used in the above table range from 40 to 45 percent for the small pumps to 70 to 74 percent maximum on the largest pump. Some pumps will operate with bowl efficiencies as high as 84 percent.

The following example illustrates a method of computing total pumping lift for centrifugal pump installation:

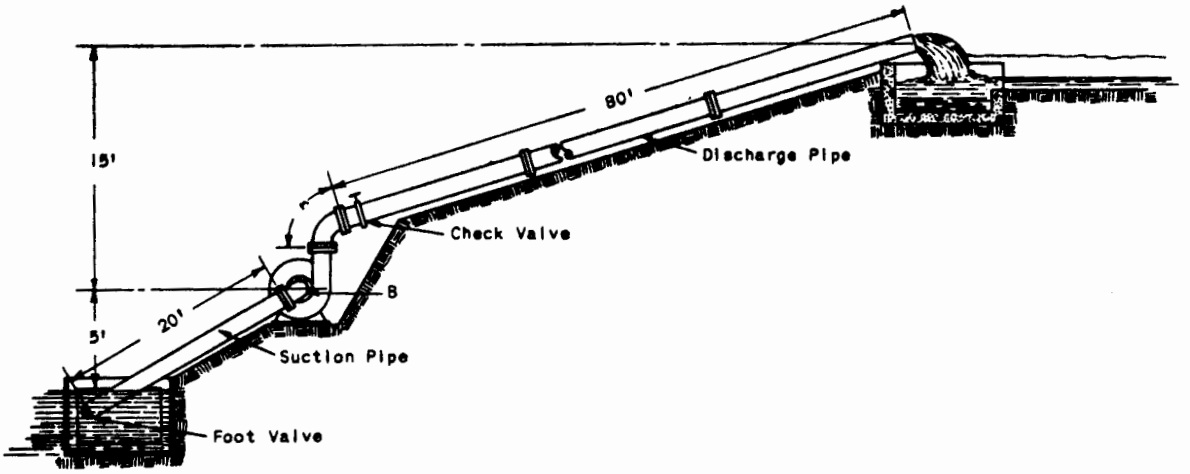


Figure 11.4

Given:

1.	Discharge capacity of pump.	1000 gpm
2.	Suction lift.	5 feet
3.	Discharge lift.	15 feet
4.	Length of suction pipe.	20 feet
5.	Length of discharge pipe.	80 feet
6.	Medium sweep elbow at A.	
7.	Standard sweep elbow at B.	
8.	Foot valve at end of suction line.	
9.	Check valve on discharge line.	

The total pumping head is the sum of the suction lift, the discharge lift, and the friction head in the pipe and fitting.

The total length of suction and discharge pipe is 100 feet. The friction loss is computed from tables in Part 16.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Centrifugal Pump (cont'd)

An examination of these tables shows the loss of head due to friction to be 12.04 feet per 100 feet for a 6-inch pipe, and for an 8-inch pipe to be 2.98 feet per 100 feet. The friction head of a 6-inch pipe is too great to permit efficient operation. The 8-inch pipe is considered best for this installation.

The friction head for 100 feet of 8-inch diameter pipe is 2.98 feet.

The friction loss in fittings is obtained from tables in Part 16, and is given in terms of equivalent lengths of pipe.

The loss in the medium sweep elbow is equivalent to 17 feet of 8-inch diameter pipe.

The loss in the standard sweep elbow is equivalent to 21 feet of 8-inch diameter pipe.

The loss in the foot valve is equivalent to 45 feet of 8-inch diameter pipe.*

The loss in the check valve is equivalent to 45 feet of 8-inch diameter pipe.*

Total loss in length of pipe is 128 feet.

The total friction head in the fitting is $\frac{128 \times 2.96}{100} = 3.81$ feet.

The total friction head in the pipe and fittings is $2.98 + 3.81 = 6.79$ feet.

The total pumping head is $20 + 6.79 = 26.79$ feet.

Turbine Pump. The performance of a deep-well turbine pump depends upon the diameter and the design of the impeller, and the speed at which it rotates. According to the fundamental laws of physics, the capacity of the pump will vary directly as the speed; the pressure head will vary as the square of the speed; and the power required will vary as the cube of the speed.

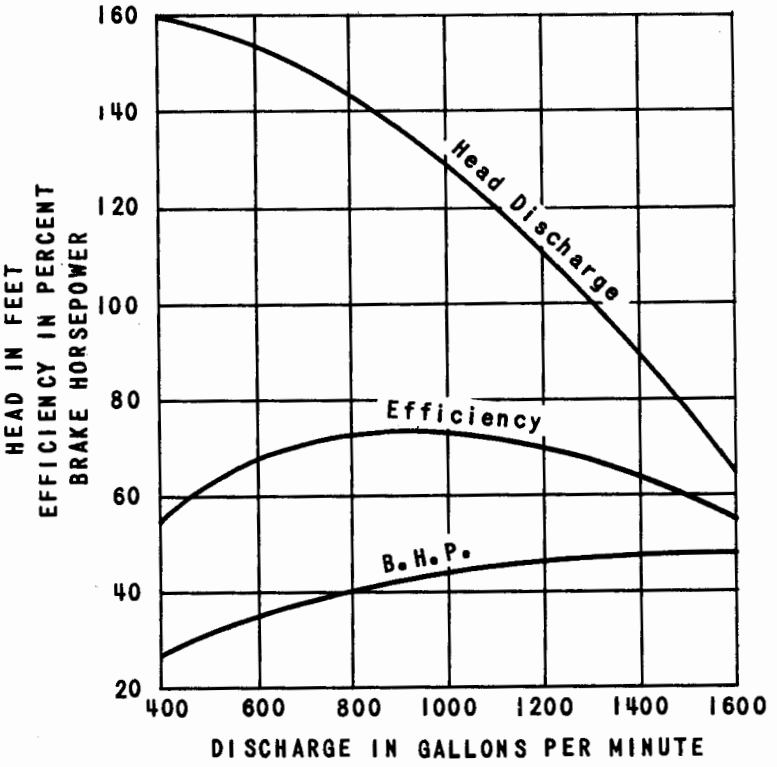
*Equivalent to 10 times gate valve fully open.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Turbine Pump (cont'd)

The efficiency of a deep-well turbine pump operating at a constant speed varies with the capacity and lift. A typical characteristic curve for a single speed is shown in Figure 11.5. The form of such curves can be varied by the design of the impeller. The efficiency in this figure is fairly well maintained over a considerable range of discharge and pumping heads. The discharge delivered by such a pump, operating at constant speed, increases as the lift decreases. The brake horsepower increases somewhat with the increase in discharge as the changes in efficiency and lift are not sufficient to counterbalance the change in discharge. The impeller may be designed so that the discharge does not increase so rapidly with reductions in lift and thus an increase in the brake horsepower required at lower lifts may be avoided. This is an advantage where electric motors are used, as overloading and overheating are avoided. Impellers may also be designed with a higher efficiency over a narrower range of discharges, with more rapid decreases in efficiencies under both larger and smaller heads. For general irrigation use in this region from wells where fluctuations in lift frequently occur, impellers with flatter efficiency curves will usually give higher average efficiencies for all season operation.



TYPICAL CHARACTERISTIC CURVES FOR DEEP WELL TURBINE PUMP OPERATING AT A CONSTANT SPEED

Figure 11.5

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Turbine Pump (cont'd)

Pumps are obtainable that will operate at 80% field efficiency and one should be specified that will at least approach this figure. Dealers should be required to furnish guaranteed field performance curves on the pump they are offering for the job.

It is important that seasonal fluctuations in water table be carefully determined by studies of adjoining wells to determine the maximum drawdown. The bowls of a turbine pump should be placed below the drawdown point. Although a pump is capable of drawing the water below the bowls by drawing on the suction, it is better to have the suction lift in reserve against a possible future lowering of the water table.

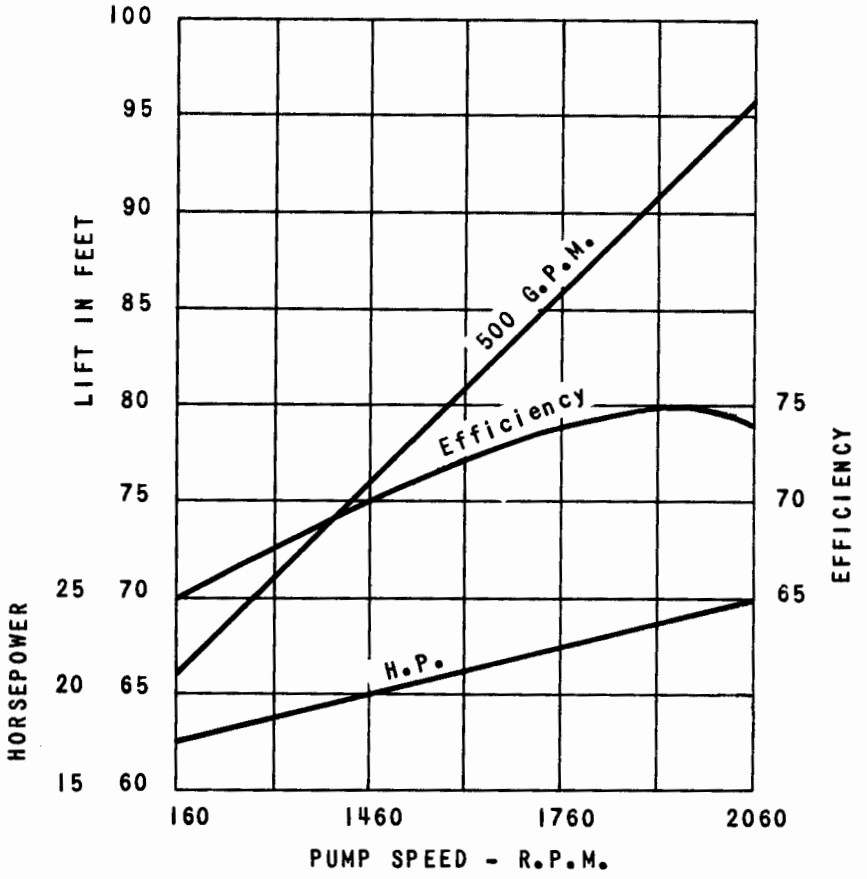
In locations where fluctuations are apt to occur, and it is important that a constant discharge be maintained over the anticipated pumping range, a power unit with variable speed must be used. The discharge will vary with the lift.

Some drillers like to set the pump discharge pipe high so that grading around the well will keep out all surface water. Instead of this, some means of sealing off surface water should be provided to allow the discharge pipe to be set low. A low discharge pipe will greatly facilitate the dissipation of energy in the pump stilling box, and also reduce the pumping lift.

A typical characteristic curve for a variable-speed, constant-discharge pumping plant is shown in Figure 11.6. This type of installation requires a power unit of sufficient size to deliver the specified quantity of water at a maximum pumping head without overloading. This may mean that the required horsepower for maximum lift may be considerably higher than that required for the initial pumping head.

The deep-well turbine pump as constructed today is fairly well standardized, both as to materials used and general assemblage. Units offered by the various competing manufacturers generally conform with the pump standards set forth by the Hydraulic Institute. Probably the greatest difference between the manufactured units is in the method of lubrication. Some companies offer oil-lubricated pumps, others offer water-lubricated, and some offer both. Both types have been operating successfully for several years. Unless local conditions warrant exclusion of one of these types, the specifications should be so written as to allow bidding on both types. Wells producing fine sand should be equipped with an oil lubricated pump. Water for domestic use must be free of oil and since oil-lubricated pumps waste some oil into the water, it is important that water-lubricated pumps be used. Each manufacturer has developed a series

2. IRRIGATION WELLS AND PUMPS (CONT'D)



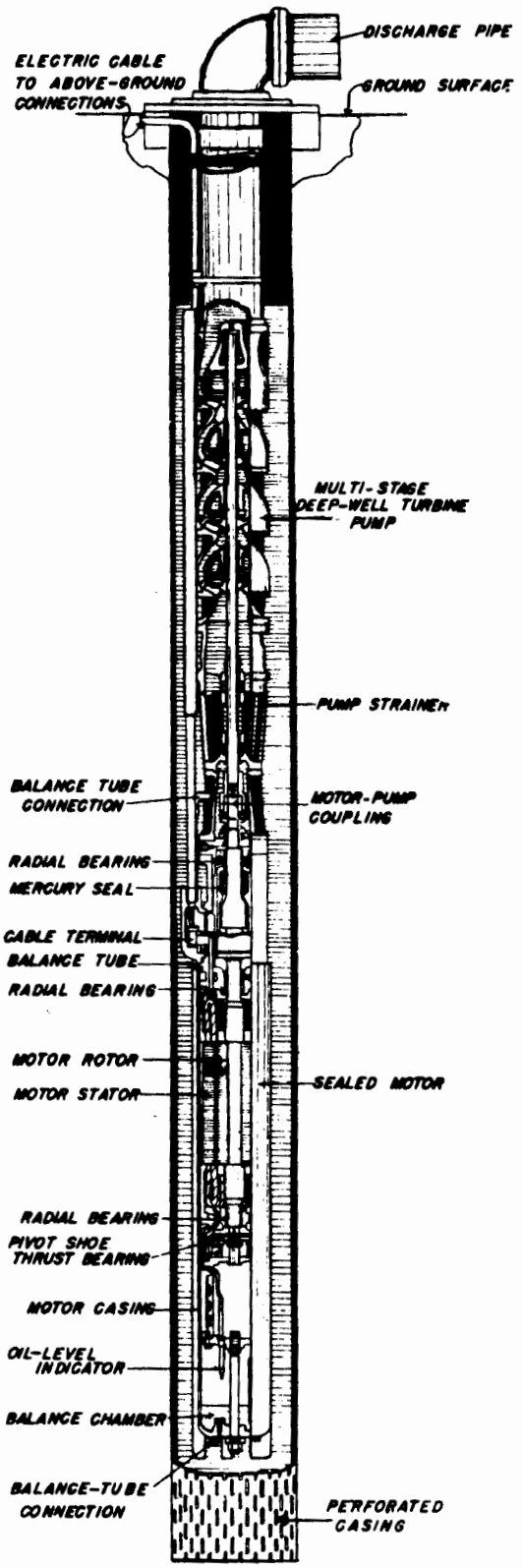
HEADS AT WHICH A TYPICAL 10" TURBINE PUMP WILL DELIVER 500 G.P.M. TOGETHER WITH RELATED FACTORS OF PUMP

Figure 11.6

Pumping Plant (cont'd)

Turbine Pump (cont'd)

of pump bowls through laboratory tests that have definite characteristics. The endeavor is made to develop a series such that these bowls may be used singly or, more commonly, in a series to meet any combination of head and discharge that may be specified with a reasonably high efficiency. Bidding generally is quite close between the various companies. Possibly the biggest difference between some bids lies in efficiencies guaranteed over the range of pumping heads and discharges specified. Quite often one manufacturer may be able to meet a specified range of discharge and lift with a set of bowls at the peak of their performance curve while another manufacturer may have to utilize a set of bowls that are operating to one side or the other of their best performance to meet the well conditions specified. A special application of a deep well turbine with submersible motor is shown in Figure 11.7.



Certain conditions call for a turbine pump with a direct-connected motor placed below the impeller. As may be seen from the sketch, the motor is submerged and is of small diameter so it can be placed in any casing which the pump bowls will enter.

The motor is enclosed in a steel case filled with a light oil of high dielectric strength. A mercury seal directly above the armature prevents oil leakage or water entrance at the point where the drive shaft passes through the case to the impellers.

Hydrostatic pressures on each side of the oil bath surrounding the motor are kept in balance by the balance tube which connects the water above the mercury seal to the balance chamber below the oil at the bottom of the motor case. The motor is cooled by contact of well water with the sealed outer casing.

The long armature of small diameter results in characteristics which are well adapted to deep-well turbine operation. A watertight conduit houses the electric cables leading from the motor to the starting box on the ground surface.

This type of pump is well adapted to meet the following conditions:

1. *Installation in a well which has a crooked bore and in which the ordinary deep-well turbine might not operate. The pump column of the conventional turbine must be perfectly straight or the shaft will crystallize and rupture.*

2. *Installation near a stream which is subject to severe flooding. Since this pump has no above-ground working parts, the well can be sealed, while the starting box, meter, and transformers can be placed above high-water level on a pole.*

3. *Installation on public grounds where an above-ground pump house or machinery would be unsightly.*

THE DEEP-WELL TURBINE WITH SUBMERSIBLE MOTOR

Figure 11.7

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Turbine Pump (cont'd)

The selection of the proper sizes of pump column and shaft, type and number of bowls, spacing of bearings and spiders, etc., and the matching of the various units of the pump to meet all well conditions, has defied all attempts at simplification and standardization. Most companies offering deep-well turbine pumps in competition have built up their own data from which the various parts of the turbine pump are selected and matched to meet a specific condition. These data are both voluminous and fairly complicated.

To specify limiting sizes of pump column and shafting, materials used, etc., may result in pump installation that is more costly, and in some cases, less efficient than could be obtained if the matching of the pump assemblage is left to the bidder. If guaranteed efficiencies and complete description of the unit as bid is specified, it is felt that sufficient data will be obtained from which a proper comparison can be made.

The water level measuring device may be eliminated if local conditions warrant it. However, in general it is felt that this addition is justified because the operator is thus able to keep informed of ground water conditions and to anticipate pump repairs and replacements.

The following information is usually desired by pump manufacturers so that they can determine the type and size of pump needed to fit the characteristics of the well:

Depth of well	_____	feet
Inside diameter of well casing	_____	inches
Depth to static water level	_____	feet
Depth to water level when well is pumped to capacity	_____	feet
Drawdown	_____	feet
Seasonal fluctuation in water table	_____	feet
Capacity of pump	_____	gpm
Speed of pump	_____	rpm
Is suction pipe to extend to bottom of well?	_____	
Strainer	_____	

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Turbine Pump (cont'd)

Type of Drive - Vertical Electric Motor:

- Voltage. . . . . _____
- Phase. . . . . _____
- Cycles . . . . . _____
- rpm. . . . . _____

Vertical Pulley:

- Horsepower of motor, engine, or tractor . . . . . _____
- Flat or V-Belt . . . . . _____
- Driving pulley diameter. . . . . _____
- Driving pulley speed . . . . . _____

Right-Angle Gear Drive:

- Horsepower of motor, engine. . . _____
- Driving shaft diameter . . . . . _____
- Driving shaft speed. . . . . _____

Drive Mechanisms. The efficiency of the drive mechanism may greatly affect the operating costs of a pumping installation. Usually one of four common types of drive is used: direct, flat-belt, V-belt, or 90-degree gear head. Experience has shown that the most efficient drive possible under prevailing conditions has proven to be the most economical in the long run. The flat-belt drive to tractor power is the least desirable and should be recommended only as a last resort as the tractor is invariably being used for some other purpose when it should be driving the pump.

The direct drive shown in Figure 11.8 is the cheapest and most efficient type of drive for electrical installations. Where electricity is dependable and is available at a reasonable rate, it is a very satisfactory source of power for irrigation pumps. The low cost of electric motors, their reliability, high efficiency, compactness, low cost of upkeep, and the limited attention they need when in operation make them especially desirable where much water is required from a unit. Since electric motors operate at a constant speed, the discharge of the pump cannot be varied, thus extreme care must be exercised in selecting the size of the pump.

The 90° gear head drive is a dependable and efficient method of transmitting the power of a combustion engine to a turbine pump. The efficiency of this type of installation can be as high as 95% or more. These units are made to fit any standard pump and are made with a variety of gear ratios to permit the pump and engine to operate at their most efficient speeds. The original cost of right-angle gear drive exceeds the cost of V-belt or flat-belt installation.

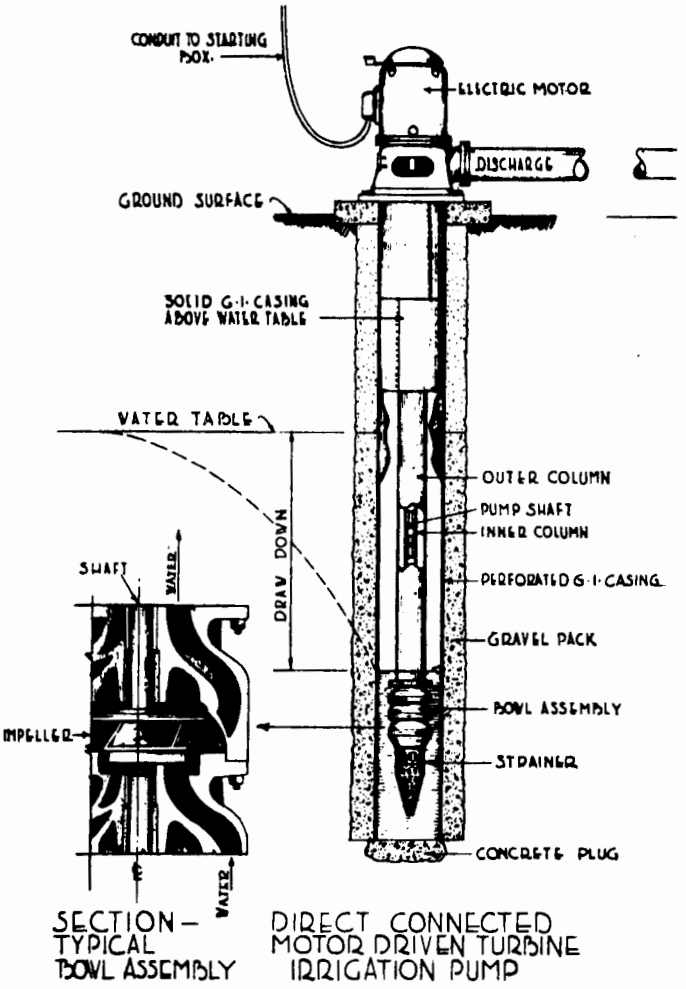
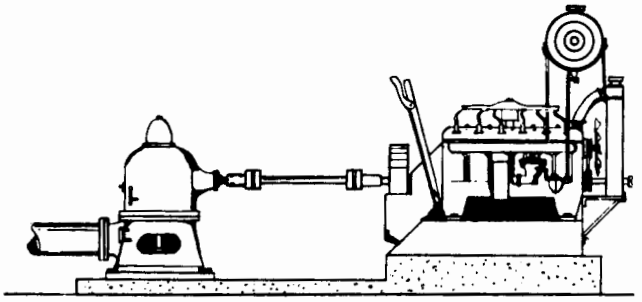


Figure 11.8



TURBINE-TYPE IRRIGATION PUMP WITH GEAR HEAD CONNECTED TO A POWER UNIT WITH A SHAFT AND DOUBLE UNIVERSAL JOINT

Figure 11.9

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Drive Mechanisms (cont'd)

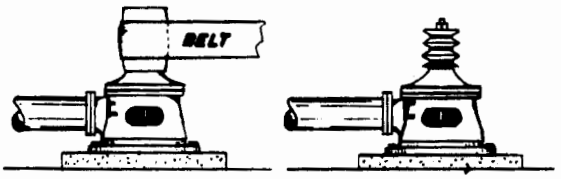
A shaft with double universal joints to connect the engine with the gear head is recommended. The shafts of the engine and gear head should be parallel when viewed from any position (in vertical or horizontal plane), however, one may be above or below the other 1/4-inch per foot of connecting shaft. A typical layout is shown in Figure 11.9.

The flat-belt drive is used in some sections of the area. It is the least expensive of the pump drives. A typical layout is shown in Figure 11.10.

Power to drive the pump may be from any source which is practical for the particular job. Stationary internal combustion engines, either gas or diesel, or electric motors are used.

A belt-driven installation requires considerable attention because the variation of temperature and humidity between morning and midday or day and night affects the tension on belt and running position on pulley. A low belt may cause edge rubbing on the mounting and damage the belt. Excessive tightness will decrease the life of the belt.

The efficiency of a flat-belt varies from 80% to 98%, depending on slippage, type of pulley and belt, pulley size, number of idlers, and the twist used.



TURBINE-TYPE IRRIGATION PUMP WITH HEAVY-DUTY BELTED HEAD FOR EITHER FLAT OR V-TYPE BELTS

Figure 11.10

V-belt drives are commonly used. They can be used under many conditions where a flat-belt drive will not serve the purpose. Deep grooved pulleys are recommended for V-belt drives. It is important that proper belt, pulley size, and alignment are used. It is best to have the V-belt manufacturer make the design for each particular installation. The bottom of the engine or motor pulley should be in a horizontal plane with the center of the pump pulley. In top view, the tight side of the belt on the pump pulley should be in line with the center of the engine pulley. A V-belt installation is slightly higher in cost than flat-belt, however, it is less expensive than a right-angle gear drive.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Drive Mechanisms (cont'd)

Dependability and efficiency will usually justify its use over a flat-belt installation. An efficiency of 95% to 99% is possible for a V-belt drive.

Pumping Head. The pumping head is defined as the total head under which a pump operates. For a horizontal centrifugal pump, it is made up of the suction lift, measured from elevation of water in sump to the centerline of the pump, the discharge lift measured from the centerline of the pump to the surface of the water in the discharge basin and the friction loss in the pipe measured from the end of the suction to the end of the discharge. It will be noted that the water is raised the distance indicated by the suction lift by the difference in pressure that exists between the suction inlet of the pump and the surface of the water in the sump. As the pressure on the water at sea level is one atmosphere or 34 feet, the highest theoretical suction lift is 34 feet less friction losses. This maximum theoretical suction lift cannot be obtained under actual conditions. The maximum practical suction lifts at various elevations are:

Elevation Above Sea Level - Feet

Sea Level	2000 Ft.	4000 Ft.	6000 Ft.	8000 Ft.
18	17	16	14	13

The basis of manufacturers' guarantees are usually for a suction head of 15 feet at sea level.

The pumping head of a deep well turbine pump and a submerged vertical centrifugal pump is measured from the water surface in the well when the pump is pumping at the specified capacity to the elevation of the water surface at the point of discharge. If the water is carried any distance in a pipe beyond the pump discharge, the friction in the pipe is computed, translated into feet and added to the measured head. All losses in the pump and pump column are included when the overall efficiency is determined.

Drawdown. As indicated before, the drawdown of a well is an important factor in operating costs and has a direct bearing on the type of pump that is installed. When a well is drilled, the water rises to a certain level, depending on the hydrostatic pressure exerted in the water-bearing strata that are intercepted. In order to create flow, a certain head will have to be developed to force water into the well. This head is called the drawdown. The drawdown of a well is variable, depending on the rate of pumping, the quantity of water contained in the strata cut by the well, and porosity of the water-bearing material.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Drawdown (cont'd)

A typical drawdown curve for a well is shown in Figure 11.2. The drawdown varies in proportion to the rate of pumping in the average well. Thus, when the drawdown is known for three or more rates of pumping, the drawdown for other intermediate rates can be closely estimated.

Power Requirements. The water horsepower required to drive a pump can be determined by the following formula:

$$whp = \frac{gpm \times h}{3960}$$

Water horsepower is the theoretical horsepower required without consideration to efficiency where:

gpm = gallons per minute pumped

h = head or lift in feet, from pumping surface of water in well to centerline of pump discharge.

In order to determine the actual horsepower required, it is necessary to know the overall efficiency of the pump, the losses in the piping system and the efficiency of the drive as well as the head under which the pump operates. The actual horsepower required may be determined by the following formula:

$$bhp = \frac{gpm \times h}{3960 \times e}$$

where bhp = actual horsepower required from power unit

gpm = gallons per minute pumped

h = head or lift in feet, including pipe line head from friction

e = overall pump efficiency or the efficiency of pump from inlet to discharge times the efficiency of the drive (see Figure 11.11).

The manufacturer will make guarantees on efficiencies that can be obtained for the pump he proposes to furnish. They can be checked in the field under actual working conditions by a number of tests. Drive efficiencies are well enough established to enable accurate assumptions to be made for the various types in common use. No drive loss is considered for direct connected vertical shaft electric motors.

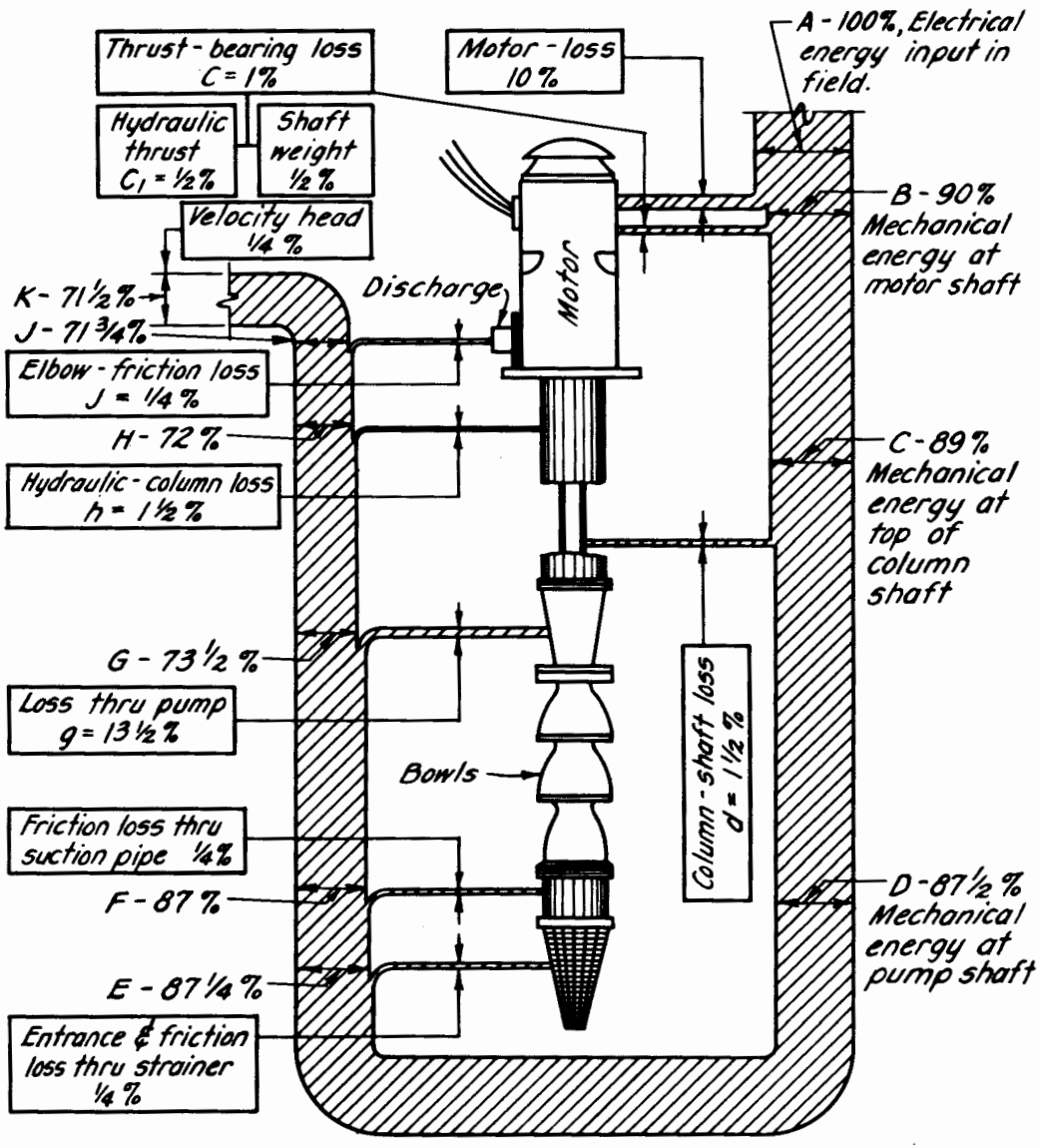

Thrust - bearing loss C = 1%
Motor - loss 10%
A - 100%, Electrical energy input in field.
Hydraulic thrust C1 = ½%
Shaft weight ½%
Velocity head ¼%
B - 90% Mechanical energy at motor shaft
K - 71½%
J - 71¾%
Discharge
Motor
Elbow - friction loss J = ¼%
H - 72%
Hydraulic - column loss h = 1½%
C - 89% Mechanical energy at top of column shaft
G - 73½%
Loss thru pump g = 13½%
Bowls
Column - shaft loss d = 1½%
Friction loss thru suction pipe ¼%
F - 87%
D - 87½% Mechanical energy at pump shaft
E - 87¼%
Entrance & friction loss thru strainer ¼%

Figure 11.11 *

HEAD LOSSES IN A DEEP - WELL TURBINE

Figure 1 depicts a deep-well turbine driven by an electric motor. A definite amount of electrical energy is supplied to the motor indicated by the width of the energy ribbon at A. In the motor, electrical energy is transformed into mechanical energy. In this process some energy, from 10 to 15 percent, is lost. Mechanical energy is transformed into hydraulic energy by the pump and additional energy is lost. The energy ribbon is narrowed by other losses, as that in the column shaft, strainer, suction pipe, and elbows, and also in velocity head. While 100 percent energy is delivered to the motor (fig. 1), only 71½ percent is actually accounted for in raising water from the well. The plant efficiency is thus 71½ percent.

Many terms are used with regard to efficiency and they may be explained from the chart in figure 1.

Pump bowl efficiency	=	$\frac{G}{F}$
Laboratory pump efficiency	=	$\frac{K+h}{D+C_1}$
Laboratory over-all efficiency	=	$\frac{K+h}{A}$
Field (pump) efficiency	=	$\frac{K}{C}$
Plant efficiency	=	$\frac{K}{A}$

The manufacturer is interested in the laboratory efficiencies whereas the user is interested in the over-all plant efficiency.

The term <u>field (pump) efficiency</u> is intended to depict the efficiency of the pump unit, completely installed with the exception of the motor. Since actual determination of this efficiency can be accomplished only by using a calibrated motor, the term field (pump) efficiency must usually be considered as calculated and is expressed as shown above, namely $\frac{K}{C}$.

<u>Plant efficiency</u> is calculated when all losses are taken into account in the complete pump and motor assembly and is expressed by $\frac{K}{A}$. This is sometimes known as the wire-to-water efficiency.

* Drawing used by permission of Byron Jackson Co., Berkeley, Calif.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Power Requirements (cont'd)

It can be noted readily that the efficiency of the pumping unit is dependent on the efficiency of each individual component of the whole. The efficiency of a pump is governed largely by its type, speed, lift, and output. Each pump is designed to function at its best efficiency when the speed, lift, and output are properly balanced. Any considerable change in any one factor will produce a corresponding reduction in efficiency. Great care should be taken to insure that the operation of a pumping installation is in accordance with the original designs. Purchase of secondhand pumps should be preceded by thorough investigations to determine if the pump will operate effectively under the new conditions imposed.

Power Units. Power for driving pumping plants is derived from one of two sources, electric motors or internal combustion engines.

Electric motors may be considered to be 88% efficient. Each motor carries a name plate giving its horsepower rating, which is the rating to be used in the selection of a motor to fulfill plant requirements. To illustrate computations necessary, assume an electric motor-driven pumping installation has a motor efficiency of 88%, a pump efficiency of 75%, and a direct connected vertical shaft drive. The overall efficiency of the plant would be 88% x 75% = 66%. The pumping rate is 450 gpm and the total pumping head (h) is 30 feet. The power that the motor must deliver is:

$$\frac{450 \times 30}{3960 \times 0.75} = \frac{13500}{2970} = 4.54 \text{ hp}$$

The next largest standard size motor should be selected which, in this case, is 5 hp.

Since one horsepower is equal to 0.746 kilowatts, the power requirement of the plant would be:

$$\frac{4.54 \text{ hp} \times 0.746 \text{ kw/hp}}{0.88} = 3.85 \text{ kw}$$

Thus for every hour the plant is operated, the power used would be 3.85 kilowatt hours.

Internal combustion engines are generally rated on their maximum brake horsepower for intermittent loads (advertised horsepower). Some manufacturers also give a brake horsepower rating for continuous load, which usually is about 80% of the maximum. The continuous load rating is the one to be used in figuring the size of engine needed for a pumping plant. When the continuous load rating is not given for an engine, use 80% of the maximum.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Power Units (cont'd)

All ratings should be based on an engine speed (rpm) that will not exceed a piston travel of more than 1400 feet per minute. For piston travel in feet per minute for various rpm and stroke in inches, see Figure 11.12.

Internal combustion engines develop more power at sea level pressure than at the reduced pressures of higher altitudes. Only that fuel can be utilized for which there is sufficient oxygen to allow for complete combustion. As altitude increases, the density of the air decreases and, therefore, the amount of oxygen decreases. The volume of fuel that can be burned and the horsepower developed likewise decreases. Engines also develop more power at lower than at higher air temperatures.

To correct continuous load engine ratings for temperature and altitude other than standard (sea level at 60° F.) use the following:

Air temperature: (approximate)

(1) Deduct 1% of rated power for each 10° F. above 60° F.

(2) Add 1% of rated power for each 10° F. below 60° F.

Altitude: (approximate)

(1) For all engines except as noted in (2) below, deduct 3% from sea level rating for each 1000 feet of altitude above sea level.

(2) For a two stroke cycle diesel engine with forced air injection, deduct 1% for each 1000 feet above sea level.

The continuous load horsepower ratings for internal combustion engines are calculated using the above adjustments.

For example, if a pump is required to deliver 1000 gallons per minute with a total lift of 50 feet and the combined pump and drive efficiency is 70%, the following power must be provided:

$$\frac{1000 \text{ gpm} \times 50 \text{ feet}}{3960 \times 0.70} = \frac{50{,}000}{2772} = 18.0 \text{ hp}$$

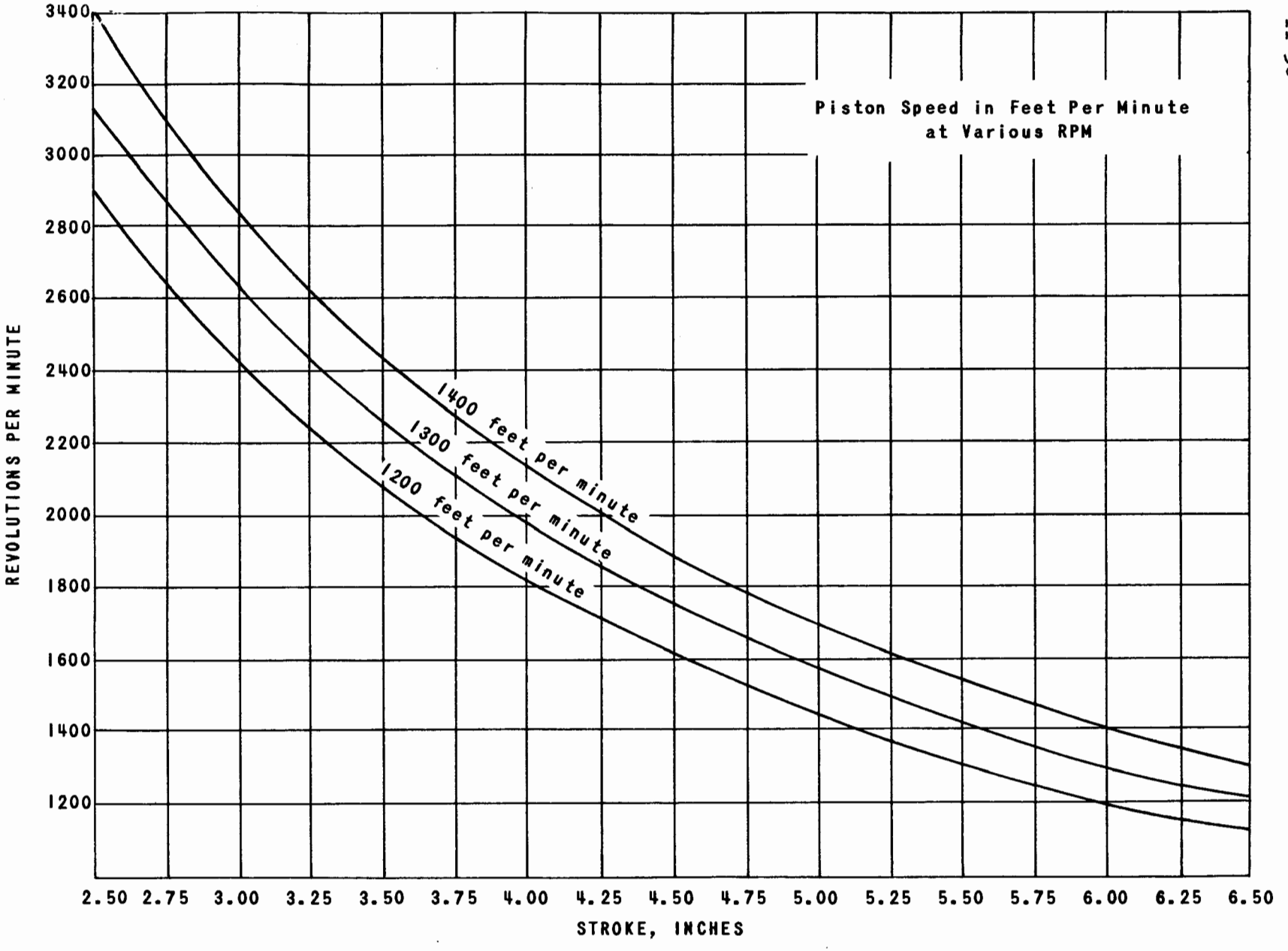

Piston Speed in Feet Per Minute
at Various RPM
REVOLUTIONS PER MINUTE
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1400 feet per minute
1300 feet per minute
1200 feet per minute
2.50 2.75 3.00 3.25 3.50 3.75 4.00 4.25 4.50 4.75 5.00 5.25 5.50 5.75 6.00 6.25 6.50
STROKE, INCHES

Figure 11.12

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Power Units (cont'd)

It is proposed to use an internal combustion engine having a maximum horsepower rating at 28.9 hp with a maximum air temperature of 100° F. and at an elevation of 3000 feet above sea level. Then the continuous load rating for the engine is calculated as:

Continuous load at sea level (60° F.)	= 28.9 x 0.80	=	23.12
Correction for temperature (-4%)		=	-0.92
Correction for altitude (-9%)		=	-2.08
			20.12

Since this continuous load capability is slightly above the power required, this engine is satisfactory.

Housing for an internal combustion engine or motor is not recommended during the operating season because of the restriction of air circulation. Cool air at the intake increases the efficiency of operation of an internal combustion engine. However, it is advisable to house the power unit during the off season.

Standards for estimating power requirements of new installations and evaluating the efficiency of an existing installation are found in Figures 11.13, 11.14, and 11.15.

Cost of Pumping. It is beyond the scope of this handbook to give actual costs of pumping plant installations that will be applicable to a specific field condition. It is desirable, however, to point out all the factors that should be taken into consideration in computing the cost of pumping the water at the outlet of the pump. The costs given in the following example are for illustration purposes only but are representative of procedures by which costs may be obtained under similar conditions. Close estimates of equipment and construction costs may be prepared by consultation with manufacturers and review of past installations, so that the actual pumping costs are within the limits anticipated.

PERFORMANCE STANDARDS FOR NEW DEEP-WELL PUMPING PLANTS		
Energy source	Rated load hp-hr/gal for representative power units	Performance standard in whp-hr/gal[1]
Diesel	14.75[2]	11.06
Gasoline	11.30[2]	8.48
Tractor fuel	11.08[2]	8.31
Propane	8.92[2]	6.69
Natural gas	88.9[3] per 1000 cu. ft.	66.4 per 1000 cu. ft.
Electric	88 per cent efficient	0.885[4] per kw-hr.

[1] Based on pump efficiency of 75 per cent.

[2] Taken from Test D of Nebraska Tractor Test Reports. Drive loss for flat belt is included.

[3] Manufacturer's data corrected for 5 per cent drive loss.

[4] Not corrected for drive loss. Assume a direct connection.

Figure 11.13

MAXIMUM FUEL REQUIREMENTS FOR A GOOD PUMPING PLANT[1]

Flow of water in gallons per minute	Lift in Feet[2]	Fuel required in gallons per hour				
		Propane	Diesel	Gasoline or tractor fuel	Natural gas[3]	Electricity[4]
500	100	2	1¼	1½	190	14
	150	2-3/4	1-3/4	2¼	280	21
	200	3-3/4	2¼	3	380	29
700	100	2-3/4	1-3/4	2	270	20
	150	4	2½	3¼	400	30
	200	5¼	3¼	4¼	530	40
800	100	3	1-3/4	2½	300	23
	150	4½	2-3/4	3½	450	34
	200	6	3-3/4	4-3/4	610	46
1000	100	3-3/4	2½	3	380	29
	150	5-3/4	3½	4½	570	43
	200	7½	4½	6	760	57

[1] Based on standards in Figure 11.13.

[2] If you have a pressure at the pump discharge, add the number of feet shown in Figure 11.15 to the distance the water must be lifted while pumping.

[3] Cubic feet per hour.

[4] Kilowatt-hours per hour.

Figure 11.14

2. IRRIGATION WELLS AND PUMPS (CONT'D)

RELATIONSHIP BETWEEN DISCHARGE PRESSURE AND LIFT	
Discharge pressure in pounds per square inch	Equivalent "lift" in feet
30	69
50	116
70	162
110	254

Figure 11.15

Pumping Plant (cont'd)

Cost of Pumping (cont'd)

Fixed Costs - the following depreciation table is based upon studies made at the University of Nebraska by Mr. John Shrunk and others:

Item	Estimated Useful Life (Average)
Well and casing	20 year
Plant housing	20 year
Pump, turbine	
Bowl (about 50% of cost of pump unit)	16,000 hour or 8 year
Column, etc.	32,000 hour or 16 year
Pump, centrifugal	32,000 hour or 16 year
Power transmission	
Gear head	30,000 hour or 15 year
V-belt	6,000 hour or 3 year
Flat belt - rubber and fabric	10,000 hour or 5 year
Flat belt - leather	20,000 hour or 10 year
Electric motor	50,000 hour or 25 year
Diesel engine	28,000 hour or 14 year
Gasoline or tractor fuel engine	
Air cooled	8,000 hour or 4 year
Water cooled	18,000 hour or 9 year
Propane engine	28,000 hour or 14 year

Interest on total investment at established rate.

Taxes and insurance equaling approximately 1½% of total investment.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Cost of Pumping (cont'd)

Operating Costs - fuel requirements of various types of engines, based on the Nebraska Tractor Tests are given below:

Gasoline: stationary power units burning gasoline developed an average of 11.30 horsepower hours per gallon.

Tractor fuels: stationary power units burning tractor fuels developed an average of 11.08 horsepower hours per gallon.

Diesel: stationary power units burning diesel fuel developed an average of 14.75 horsepower hours per gallon.

Propane: stationary power units burning propane gas developed an average of 8.92 horsepower hours per gallon.

Natural gas: stationary power units burning natural gas developed an average of 88.9 horsepower hours per 1000 cubic feet.

Electric motors: electric motors at 88% efficiency developed 1.18 horsepower hours per kilowatt.

Lubricating oil: 1 gallon per 700 horsepower hours for gasoline, tractor fuel and diesel fuel; 1 gallon per 1000 horsepower hours for propane or natural gas; and 1 gallon per 2000 horsepower hours for electric motors.

Other oils and greases: $0.010 per hour of operation.

Engine maintenance and repairs:

$5.00 per year for electric motors
$0.0013 per horsepower hour for propane and natural gas
$0.00175 per horsepower hour for tractor fuel and gasoline
$0.0021 per horsepower hour for diesel.

Attendance: $5.00 per year for electric motors, 4% of total operating hours times $1.00, or $0.04 per hour of operation.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Cost of Pumping (cont'd)

A sample cost analysis of a complete pumping installation using propane fuel follows:

Altitude		4000 feet
Operating temperature		100° F.
Depth of well		70 feet
Pumping lift		50 feet
Pumping rate		1000 gpm
Area irrigated		100 acres
Water pumped		150 acre feet
Turbine pump field efficiency		75 percent
Drive efficiency (direct connected 90° gear head)		95 percent
Overall pump and drive efficiency	.75 x .95 =	71.3 percent
Horsepower required at drive		17.7 hp
Continuous load horsepower rating required of engine (efficiency of 17.7 horsepower engine reduced 12% for altitude and 4% for temperature)		21.0 hp
Horsepower hours per gallon of fuel		8.9 hp-hr/gal
Time required to pump one acre-foot of water: $\frac{43{,}560 \text{ cu ft (1 acre ft)} \times 7.4 \text{ gal/cu ft}}{1000 \text{ gpm} \times 60 \text{ min/hr}}$		= 5.37 hr/acre ft
Fuel consumed per hour of operation: $\frac{21.0 \text{ hp}}{8.9 \text{ hp-hr/gal}}$		= 2.36 gal/hp-hr
Fuel required to pump one acre foot of water: $\frac{5.37 \text{ hr/acre ft} \times 21.0 \text{ hp}}{8.9 \text{ hp-hr/gal}}$		= 12.7 gal/acre ft
Time required to pump 150 acre feet of water: 150 acre ft x 5.37 hr/acre ft		= 805.5 hrs
Total gallons of fuel consumed: 150 acre ft x 12.7 gal/acre ft		= 1905 gal

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Pumping Plant (cont'd)

Cost of Pumping (cont'd)

Cost of Plant:		
Well, complete - 70 feet @ $12.50 per foot. .	$ 875.00	
Pump, complete with 90° gear head	1375.00	
Engine, using propane	700.00	
Shelter	270.00	
Total Cost.	$3220.00	
Fixed Costs:		
Interest, $3220 @ 5%	$161.00	
Taxes and insurance, $3220 @ 1½%.	48.30	
Depreciation, engine, $700 @ 7%	49.00	
Depreciation, pump, $1375 @ 8½% overall . .	116.88	
Depreciation, well, $875 @ 5%	43.75	
Depreciation, shelter, $270.00 @ 5%	13.50	
Total Fixed Costs		$432.43
Operation Costs:		
Propane - 1905 gal @ $0.115	$219.08	
Lubricating oil, 14 gal @ $1.00	14.00	
Oil and grease, 805.5 hrs @ $0.01	8.06	
Engine repairs, 14,257 hp hrs @ $0.0013 . .	18.53	
Pump repairs, $1375 ÷ (2 x 20).	34.38	
Shelter repairs	2.00	
Attendance, 806 hours @ $0.04	32.24	
Total Operation Costs		$328.29
Total Yearly Costs		$760.72

Total cost per acre foot	$760.72 / 150	$5.07
Total cost per acre foot per foot of lift	$5.07 / 50	$0.1014
Operation cost per acre foot	$328.29 / 150	$2.19
Total cost per acre	$760.72 / 100	$7.61

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Factors Relating to Design of System

The development of an irrigation system presents many and varied problems in all technical fields if the facility is to function in an efficient and profitable manner over a period of years. Engineering, although concerned with only a part of the total problem, plays a most important part in layout, design, and operation. Where pumping plants are involved, it includes not only the design of the plant but also consideration of associated costs which, because of a distinct line of separation, are set up under two divisions.

Costs are logically divided into "Fixed Costs" and "Operating Costs". Fixed costs represent interest on the original investment, taxes, insurance, and depreciation, all of which must be charged to the plant regardless of whether or not it is in operation. Operation costs are those which are the direct result of operation and consist of charges made for energy, lubricating oils and greases, repairs, plant attendance, etc.

Although it is not always possible to exercise a great deal of control over fixed costs, it generally is given first consideration as certain well-known factors affecting it are of vital importance. It is a natural deduction to assume that the less the initial investment, the less will be the interest, taxes, insurance, etc. Since depreciation is more or less established on a yearly basis, the more a plant operates through a given period of time, the less will be the depreciation costs per hour of operation. These factors tend to favor small plants operating over longer periods of time as they all are reflected directly into fixed costs. To further substantiate this attitude toward fixed costs, it is known that operating costs vary almost directly with the pumping head under which the plant operates.

The rate at which water must be delivered into any irrigation system may depend upon several variables, but they are all summed up into one factor, which is time. If a plant can be designed and the system so managed that a small plant operating under a low head will provide water in sufficient quantities to adequately cover a given acreage during the appropriate periods for the crops grown, it will result in the most efficient plant from the standpoint of costs in the amount of water delivered.

The quantity of water required to irrigate a given acreage of land is not always understood by the irrigators. Western water right laws are set up on the basis of providing one second-foot for each 50 to 70 acres of land. It is difficult to establish an arbitrary figure, but an estimate can be made in each particular case after the acreage and type of crop to be grown is known. Suppose, for example, that 40 acres of land are to be irrigated and that the maximum irrigation requirements during the irrigation season will be four acre-inches of water within a period of 7 days. The well then must be able to supply 14 acre-feet

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Factors Relating to Design of System (cont'd)

during the period of 7 days of continuous pumping or at the rate of approximately 1 cubic foot of water per second. The proper evaluation of the conditions surrounding each particular installation will enable a proper decision to be made as to the quantity of water required during the peak pumping operations.

To determine whether a system is economically feasible and if it will result in a profitable enterprise, it is necessary to convert all costs to a per-acre basis. Consequently, to keep these costs as low as possible, it is necessary to bring as much acreage under the system as is consistent with good management. Although there is a limit to the expansion of any system, the most decisive factor is the operator's managerial ability to carry out a good plan of operations as prepared by the farm planner. The best any planner can do is analyze the resources of the operator, including individual ability for application, available labor, and the seasons of the year such labor will be available. From this, an effort should be made to obtain a balance between "time" and acreage. By no means should an effort be made to include all irrigable land if it appears beyond the possibilities of proper management. As the peak point in plant design is at the highest specific yield of the well, this point should never be exceeded, and plants should not be over-designed in an attempt to justify large acreages.

There are various approaches to the problem of increasing acreage served by small plants. All of them, however, depend on proper planning and the managerial ability of the operator, and should be thoroughly understood before undertaken. Those most frequently employed are shown below:

1. Early spring and late fall irrigation to store water in the soil for plant use during the growing season.

2. Diversifying crops in a manner that will distribute water requirements through different periods of the season, permitting operation of the plant over a longer period.

3. Plan for the use of certain crops having a small demand for supplemental water on parts of the acreage.

4. Plan on utilizing the facility 24 hours a day, either direct from the plant or through the medium of a reservoir which will permit around-the-clock pumping. The use of a reservoir is recommended only where the yield of the well is less than the amount of water which can be properly distributed, so that distribution can be made properly during the hours allotted for it.

2. IRRIGATION WELLS AND PUMPS (CONT'D)

Outlet Protection

Water is discharged from the pump at a relatively high velocity. In order to obviate erosion in the main channel and to remove the possibility of undermining of the pump foundation, it is necessary to construct stilling basins at the pump discharge. The basin or box usually is built of concrete, although timber or metal structures will function equally well. Old stock water tanks, sections of boilers, or other similar scrap material may be utilized. The box should have enough cross sectional area and a great enough length to reduce the velocity to reasonable limits. The outlet openings should be protected at the transition to the canal for a short distance as the turbulence resulting from the change in section will cause serious erosion. A plan of a combination stilling basin and division box is shown on Figure 11.16.

Battery Installation

There are many localities where water is obtained near the surface from a shallow water-bearing formation. Such formation may have a low specific yield and a single well usually will not yield the required quantity of water. It is then necessary to consider a battery installation.

Battery installation consists of two or more wells operated by one pump. Figures 11.17 and 11.18 show typical 3 and 4 well battery installations. The wells should be placed far enough apart so there is little or no interference when the system is being pumped at the desired capacity. Usually wells spaced 60 feet apart will function satisfactorily. Wells should be placed across the direction of ground water movement.

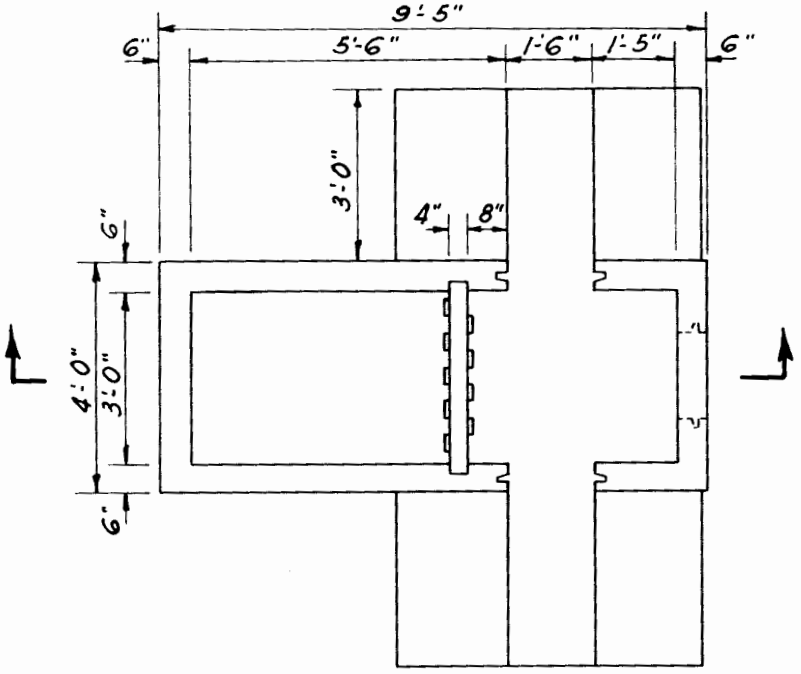
The advantage of a battery installation is that only one pump is required and since a large size centrifugal develops higher efficiency than a small one, this means less operating cost.

3. DOMESTIC WELLS AND PUMPS

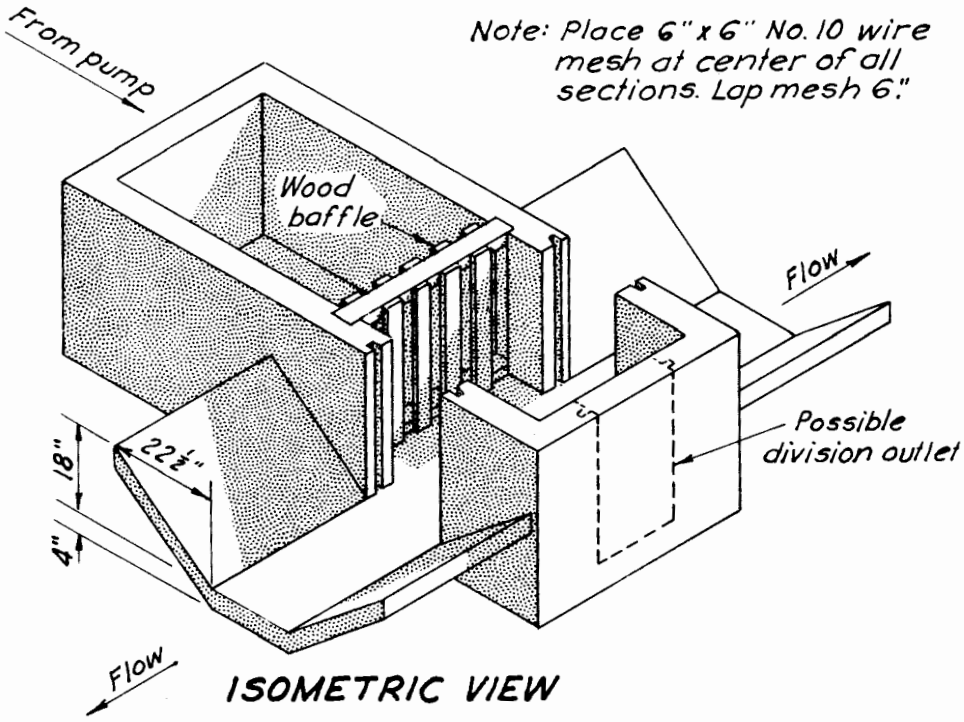
Types of Wells

There are three general types of wells: dug, driven, and drilled. The method used in constructing a well depends largely on the depth to which it must be carried, the elevation of the ground water table, and the nature of the material encountered in the hole.

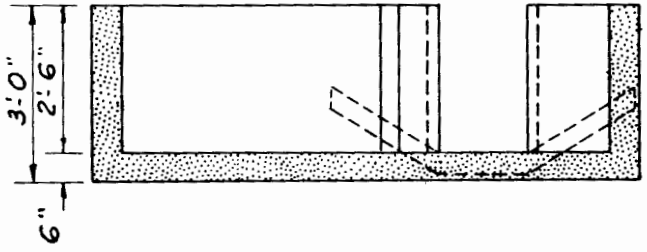
Dug wells are constructed by digging down to water-bearing strata. The open excavation is usually circular in shape and from three to five feet in diameter. Before modern well drilling equipment was available, most wells were dug. However, under present day methods driven or drilled wells are in most cases far more satisfactory and economical.



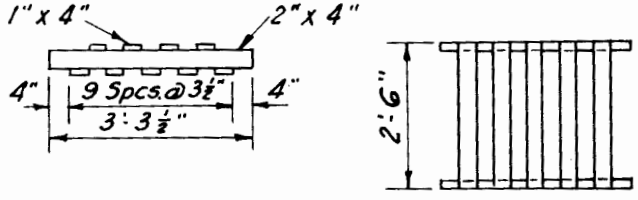
PLAN



ISOMETRIC VIEW



SECTIONAL ELEVATION

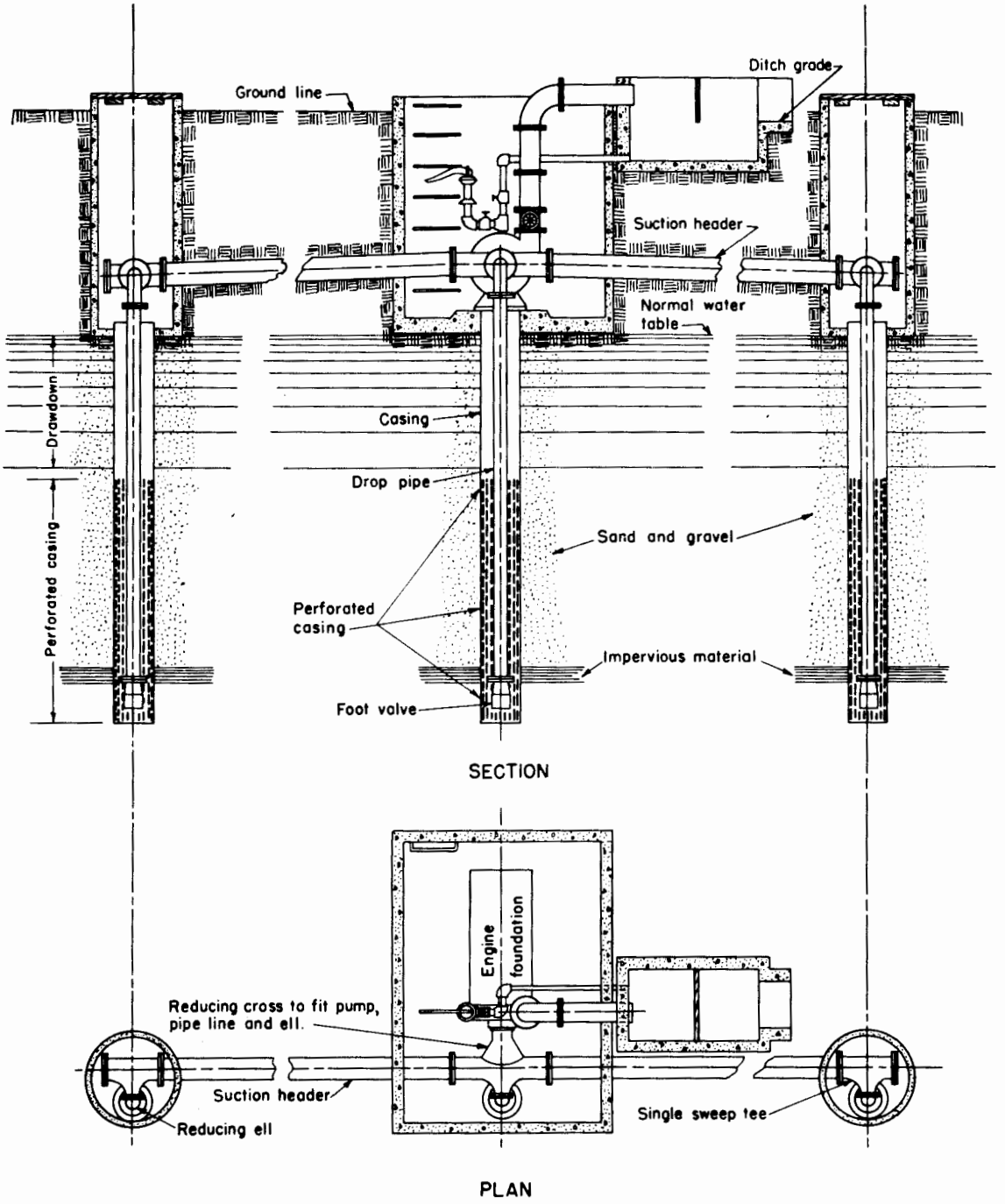


DETAIL OF BAFFLE

COMBINATION PUMP OUTLET AND DIVISION BOX

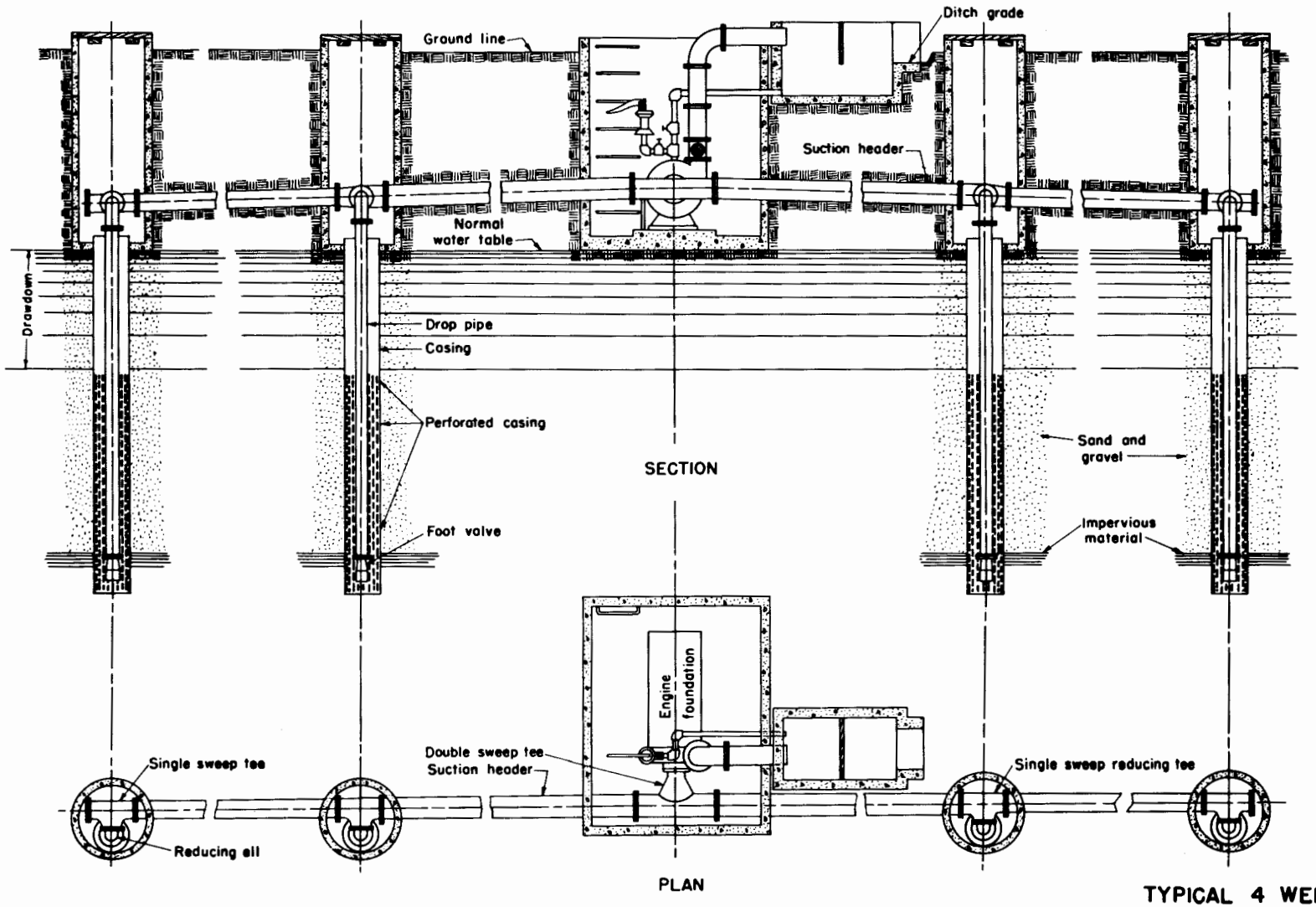
Capacity - 1050 - 1600 G.P.M.

Figure 11.16



TYPICAL 3 WELL BATTERY INSTALLATION

Figure 11.17



TYPICAL 4 WELL BATTERY INSTALLATION

Figure 11.18

3. DOMESTIC WELLS AND PUMPS (CONT'D)

Types of Wells (cont'd)

A driven well, as the name implies, consists of a special point and screen assembly that is attached to a casing and driven to a water-bearing strata. This type is only adapted to relatively shallow wells. In sandy soils, wells have been driven to depths up to 60 feet. The three most common methods employed in sinking the well are: attaching a sandpoint to the end of a pipe and driving it to the required depth; forcing the pipe down by removal of material with a sandbucket or pump; or by jetting the material away from the end of the pipe to permit it to penetrate to the desired depth. The latter also is referred to as the jetting method of installation and is used for small diameter wells up to 100 feet deep.

A drilled well is suited to any type of material or depths. It is constructed by standard equipment which consists essentially of a derrick, a power plant, and a string of tools. This type of well must be constructed by an experienced person who has the necessary equipment.

Well Location

Factors to be considered in locating a well are:

1. Locate the well so the natural drainage from barns, chicken houses, hog pens, "stomp" lots, toilets, etc., are away from the well, never toward it, to eliminate danger of contamination.

2. Locate the well above flood water elevation.

3. If feasible, locate the well at the high point and as near the point of use as possible.

4. Investigate existing supplies in proximity to well site as regards depth of hole, quality and quantity of water, pumping head, and the log.

5. Obtain information from local well drillers about wells drilled in the community, state agency or U. S. Geological Survey.

Equipment of Well

Casing. The diameter of the well or casing is governed by the quantity of water required, and by local custom. Casing diameters varying from two to four inches are recommended for this region, the exact size determined by conditions existing at the site.

Practically all wells in this region are cased the entire depth. The only exception is where the water-bearing stratum is composed of rock overlain with unconsolidated material. Under such circumstances the casing need only be extended to the rock and sealed.

3. DOMESTIC WELLS AND PUMPS (CONT'D)

Equipment of Well (cont'd)

Casing (cont'd)

New casing should be used as the life of the well is dependent on the life of the casing. The casing may be galvanized or made of black iron. Secondhand pipe previously used in connection with gas or oil developments is not satisfactory, regardless of the condition of the metal itself. Such pipe may taint the water to a degree that it is not usable. Light weight galvanized pipe fabricated from sheet metal is not recommended except in areas where local custom has proven it satisfactory. It does not have the life of standard casing, the joints are not tight enough to preclude a seepage of undesirable water into the well, and it may collapse when used in unconsolidated material. Pertinent data in weights and diameter of types of pipe used for well casing is tabulated in Figures 11.19 and 11.20.

The top of the well should be sealed by means of a concrete slab. The slab is made large enough to serve as a base for the pumping equipment. The casing should extend about 12 inches above the normal ground surface and should make a water-tight connection with the base, which is usually made about six inches thick.

Drop Pipe. All drop pipe should be standard galvanized pipe. It is advisable to use a drop pipe having an internal diameter larger than that of the cylinder or working barrel to permit removal of the valves for repair without pulling the drop pipe. The drop pipe should extend far enough into or below the water-bearing strata (aquifer) to permit the well to be pumped continuously at capacity without danger of exposing the suction.

Cylinder. The size of the cylinder (working barrel) is determined by the diameter of the well, pumping rate, well depth, and size of wheel if a windmill is used. It is good policy to design the pumping unit to produce from two to three times the total daily requirements in 24 hours, particularly when wind is used as a source of power. The capacity of most wells drilled in this region is limited, thus the size of the cylinder is governed by the discharge of the well. Always select a cylinder having a capacity somewhat less than that of the well to permit continuous pumping without danger of lowering the water to the point where the suction is exposed. Figures 11.21 and 11.22 can be used as a guide in selecting the size of cylinder for any particular well. When a hand pump is used, it is desirable to install as small a cylinder as is possible, as the larger the cylinder the more power required to operate the pump.

The loads recommended in the table are for moderate wind conditions. In localities where the winds are strong, these loads may be considerably increased. To obtain the best results in light winds, the table should be closely followed.

WEIGHTS AND DIMENSIONS OF CASING

Size	Diameters		Thick-ness	Weight Per Foot		Threads Per Inch
	External	Internal		Plain Ends	Threads & Couplings	
Standard Pipe - Black and Galvanized						
3/4	1.050	.824	.113	1.130	1.134	14
1	1.315	1.049	.133	1.678	1.684	11½
1-1/4	1.660	1.380	.140	2.272	2.281	11½
1-1/2	1.900	1.610	.145	2.717	2.731	11½
2	2.375	2.067	.154	3.652	3.678	11½
2-1/2	2.875	2.469	.203	5.793	5.819	8
3	3.500	3.068	.216	7.575	7.616	8
3-1/2	4.000	3.548	.226	9.109	9.202	8
4	4.500	4.026	.237	10.790	10.889	8
4-1/2	5.000	4.506	.247	12.538	12.642	8
Standard Black Well Casing						
2	2.250	2.050	.100	2.296	2.340	14
2-1/4	2.500	2.284	.108	2.759	2.820	14
2-1/2	2.750	2.524	.113	3.182	3.250	14
2-3/4	3.000	2.768	.116	3.572	3.650	14
3	3.250	3.010	.120	4.011	4.100	14
3-1/4	3.500	3.250	.125	4.505	4.600	14
3-1/2	3.750	3.492	.129	4.988	5.100	14
3-3/4	4.000	3.732	.134	5.532	5.650	14
4	4.250	3.974	.138	6.060	6.200	14
4-1/4	4.500	4.216	.142	6.609	6.750	14
4-1/2	4.750	4.460	.145	7.131	7.250	14

Figure 11.19

LIGHT WEIGHT GALVANIZED CASING
SCREW JOINT - DOUBLE LOCK SIDE SEAMS

Diameter Inches	22 Gage	20 Gage
	Approximate Weight Lbs. Per 100 Feet	Approximate Weight Lbs. Per 100 Feet
3	117	150
3-1/2	140	162
4	160	190
4-1/2	175	215
5	190	230
5-1/2	210	255
6	230	275

Figure 11.20

LARGEST SIZE CYLINDER THAT MAY BE USED
IN VARIOUS SIZES WELL CASING

Size of Casing	Largest Size of Cylinder and Type
2 inch	1-3/8 inch brass body flush cap cylinder
2-1/2 inch	1-7/8 inch brass body flush cap cylinder
3 inch	2-1/2 inch brass body flush cap cylinder
3-1/2 inch	2-1/4 inch brass body lined cylinder or 3 inch brass body flush cap cylinder
4 inch	2-1/2 inch iron or brass lined cylinder or 3-1/2 inch brass body flush cap cylinder
4-1/2 inch	3 inch iron or brass lined cylinder or 4 inch brass body flush cap cylinder

Figure 11.21

SIZES OF CYLINDERS ADAPTED TO DIFFERENT PUMPS
ACCORDING TO DEPTH OF WELL

	Depth of Well - Feet						
	25	50	75	100	125	150	200
	Size of Cylinder - Inches						
1. Light hand top lift pump	3	2	-	-	-	-	-
2. Medium hand top lift pump	3¼	3	-	-	-	-	-
3. Heavy hand top lift pump	4	3½	3¼	3	2½	-	-
4. Light windmill top lift pump	3	2½	-	-	-	-	-
5. Medium windmill top lift pump	3½	3¼	3	2½	2	-	-
6. Heavy windmill top lift pump	4	3½	3¼	3	2½	2¼	2

Figure 11.22

COMMON SIZES OF WOOD PUMP RODS
AND CORRESPONDING PIPE SIZES

Pump Rod (Inches)	Drop Pipe (Inches)	Wt./100 Feet of Rod With Joint
1-1/8	2	45
1-3/8	2½	75
1-5/8	3	100
1-7/8	3½	150

Figure 11.23

3. DOMESTIC WELLS AND PUMPS (CONT'D)

Equipment of Well (cont'd)

Cylinder (cont'd)

A windmill should stand at least 15 feet above all obstructions within 400 feet.

Pump Rod. The pump rod may be made of wood or steel. Figure 11.23 gives the common sizes of wood pump rods and corresponding pipe sizes.

Pump. Any standard hand pump may be used, provided it has a closed top and is adaptable for use with windmills or pump jack, as may be required.

Power Requirements. Figure 11.24 gives the approximate horsepower required to pump a given quantity of water under a given head by electricity. Always select a motor that is overpowered. This is particularly true when a gasoline engine is used. The table is given for general information only, as it is impractical to include enough data to cover all possible types of installations. Always check the motor size selected for a given installation with a reputable dealer to insure proper functioning of the unit.

Windmill. The mill should have sufficient power to pump the quantity of water specified. Figure 11.25 gives the approximate quantity of water delivered when the mill is operating in a wind strong enough to run at its maximum number of strokes. When the prevailing winds are light or variable, where the wind usually blows only a few hours each day, or where the exposure is poor, an oversized mill should be selected. Pumps and cylinders used with the various sizes of mills should be capable of giving a clear stroke equal in inches to the diameter of the windmill in feet; for example, eight inches for the 8-foot, ten inches for the 10-foot, etc. The capacities shown in Figure 11.25 are based on the long stroke of the mills. When the short stroke is used the capacity should be reduced about 25%. Use of the short stroke is not recommended except under conditions when it is required to fit an existing pump installation.

Tower. Towers may be built of either wood or steel. Wood towers have the advantage of greater stability during high winds and they do not attract lightning as much as steel. The tower should have sufficient height to put the wheel above all obstructions.

CAPACITY OF DIFFERENT SIZED CYLINDERS AND HORSEPOWER REQUIRED
FOR DIFFERENT TOTAL HEADS - SINGLE ACTING PUMP

Size Cylinder Inches	Length Stroke Inches	Stroke Per Minute	Gallons Per Hour	Horsepower Required for Total Head							
				25'	50'	75'	100'	125'	150'	200'	400'
2	6	40	196	.065	.13	.20	.25	.32	.38	.50	1.00
2	8	40	261	.08	.16	.24	.32	.40	.48	.64	1.28
2	10	40	326	.10	.20	.30	.40	.50	.60	.80	1.60
2-1/4	6	40	247	.075	.15	.23	.30	.38	.45	.60	1.20
2-1/4	8	40	330	.10	.20	.30	.40	.50	.60	.80	1.60
2-1/4	10	40	413	.13	.26	.39	.52	.65	.78	1.04	2.08
2-1/2	6	40	306	.095	.19	.29	.38	.48	.57	.76	1.52
2-1/2	8	40	408	.12	.24	.36	.48	.60	.72	.96	1.92
2-1/2	10	40	510	.16	.32	.48	.64	.80	.96	1.28	2.56
2-3/4	6	40	370	.115	.23	.35	.46	.58	.69	.92	1.84
2-3/4	8	40	493	.15	.30	.45	.60	.75	.90	1.20	2.40
2-3/4	10	40	617	.19	.38	.57	.76	.95	1.14	1.52	3.04
3	6	40	440	.14	.28	.42	.55	.69	.83	1.10	2.20
3	8	40	587	.185	.37	.56	.74	.93	1.11	1.48	2.96
3	10	40	734	.23	.46	.69	.92	1.15	1.38	1.84	3.68
3-1/4	6	40	517	.165	.33	.50	.65	.82	.98	1.30	2.60
3-1/4	8	40	690	.21	.42	.63	.86	1.07	1.28	1.72	3.44
3-1/4	10	40	862	.27	.54	.81	1.08	1.28	1.62	2.16	4.32

NOTE: The above table gives the actual hp required for operation of the pump by an electric motor. If a gasoline engine is used, add 50% to the above figures. The power stated is approximate as it is impossible to determine all of the loss of power that occurs from friction. The capacity given in the above table is based on 40 strokes per minute. To find the capacity of any size cylinder with less than 40 strokes per minute, deduct 1/40 part of the capacity given for each stroke less than 40 strokes per minute.

Figure 11.24

PUMPING CAPACITY OF MILLS

Size of Cylinder (Inches)	*Capacity Per Hour (Gallons)		Elevation in Feet to Which Water Can Be Raised					
			Size of Mill					
	6'	8' - 16'	6'	8'	10'	12'	14'	16'
1-3/4	105	150	130	185	280	420	600	1000
1-7/8	125	180	120	175	260	390	560	920
2	130	190	95	140	215	320	460	750
2-1/4	180	260	77	112	170	250	360	590
2-1/2	225	325	65	94	140	210	300	490
2-3/4	265	385	56	80	120	180	260	425
3	320	470	47	68	100	155	220	360
3-1/4	...	550	...	...	88	130	185	305
3-1/2	440	640	35	50	76	115	160	265
3-3/4	...	730	...	...	65	98	143	230
4	570	830	27	39	58	86	125	200
4-1/4	...	940	...	...	51	76	110	180
4-1/2	725	1050	21	30	46	68	98	160
4-3/4	...	1170	...	...	...	61	88	140

*The pumping capacity of the mills in the table varying in diameter from 8 to 16 feet is the same with cylinders of the same diameter. The length of stroke increases in proportion to the size of the wheel but the number of strokes per minute decreases, consequently the discharge remains constant. With the 6-foot mill, which is back-geared more than the other sizes and has a stroke of only 5-1/2 inches, the quantity of water delivered is about 30 percent less than for the other sizes. The reduction in capacity for any particular size of cylinder is compensated for in the ability of the 6-foot mill to raise water to a greater elevation than its true proportion.

Pumps and cylinders used with the various sizes of mills should be capable of giving a clear stroke equal in inches to the diameter of the windwheel in feet, i.e., 8 inches for 8-foot, 10 inches for 10-foot, etc.

The capacities shown in the table are based on the long stroke of the mills. When the short stroke is used, the capacity should be reduced by about 25%. However, the same quantity of water may be obtained by using a cylinder of larger diameter so as to increase its capacity 25%. We do not advise using a windmill on the short stroke except where the pump already in the well has a cylinder which is so large as to overload the mill if operated on the long stroke.

Figure 11.25

GPO 857257

CONTENTS

PART 12

GRADE STABILIZATION

Subject	Page
1. General	12-1
Weir or Box Type Drop Spillways	12-1
Principle or Drop Inlet Spillway	12-3
Chute Spillways (Formless)	12-5
Chute Spillways (Formed)	12-7
Irrigation Drops	12-8
2. Surveys	12-9
3. Design	12-10
4. Layout	12-11
5. Construction	12-11

LIST OF FIGURES

PART 12

GRADE STABILIZATION

Figure Number	Title	Page
12.1	Reinforced Concrete Weir Notch Structure	12-2
12.2	Sheet Steel Piling Weir Notch Spillway	12-3
12.3	Grade Stabilization Dam with Drop Inlet	12-4
12.4	Road Structure with Drop Inlet	12-5
12.5	High Velocity Concrete Chute in Grassed Waterway	12-6
12.6	Formed Concrete Chute Spillway	12-7
12.7	Concrete Irrigation Structure for Stabilizing Ditch Grades	12-8

PART 12

GRADE STABILIZATION

1. GENERAL

Stabilization of grade is a requirement incorporated into almost every soil and moisture conservation structure or measure where water flows with a free surface. Whenever a stream of water is unconfined and free to expand or contract, the grade of the channel affects the velocity of flow and to some extent the subsequent degree of erosion.

The most simple mechanical measures applied with farm machinery stabilize the grade on which the water will flow. Contour farming on cropland or contour furrows on grass lands slow down runoff and give it time to enter the ground. Level terraces do the same thing. Gradient terraces across the slope carry the water on a nonerosive grade. Each of these measures shortens the length of slope, provides temporary storage, and reduces water velocities so that soil erosion is decreased. Any outlet or waterway also reduces the velocity and decreases erosion. If the water velocities are still erosive and cannot be reduced by changing the cross section, suitable structures will be needed to reduce the grade. This can be done by using a concrete or masonry weir notch spillway, box type spillway or chute, or by the construction of an earth dam with a drop inlet tube to lower the water.

In irrigation canals and laterals, grades are stabilized by using drops or chutes.

Grade stabilization is incorporated into some structures which have another primary purpose. A detention dam is designed to store runoff water that would cause erosion or siltation of lower-lying lands or channels - or the dam may be for the protection of other structures lying below. The lowering of the water through the primary spillway or tube, provides some grade stabilization. In the same manner, a stockwater dam with a trickle tube will reduce the grade on which some of the water will flow. Grade stabilization is therefore a part of all of our soil and moisture conservation work.

Upstream measures will have an effect on the amount of water that must be carried by any structure built for grade stabilization. Application of agronomic measures to increase the intake rate of soils, as well as mechanical measures to provide temporary storage, will reduce the peak runoff and volume that must be handled. The land treatment measures will also reduce the sediment that must be stored or bypassed by the structure. Upstream protective measures must be fully applied so the structures can be designed to to store or discharge less water, have an increased life expectancy, and cost less for maintenance.

Weir or Box Type Drop Spillways

These structures are generally used in the lower reaches of water disposal systems, such as terraces, diversions, outlets, and waterways, large overfalls adjacent to streams, or for drainage.

1. GENERAL (CONT'D)

FIGURE 12.1

In these structures the water flows through a weir notch or over the lip of a box type crest. They may be made of reinforced concrete, rubble masonry, or reinforced concrete block. The water must fall on an apron and be confined by permanent walls. The walls may be sloping or straight, flared or curved. The energy of the falling water is dissipated within the structure so that the released water flows at a nonerosive velocity. Cut-off walls are provided to reduce water seepage, reduce rodent damage, and prevent undercutting of the structure.

The structures are very effective when properly designed, but are limited to low heads, normally up to eight feet. They can be used to stabilize gullies, outlets and waterways, or an overfall that is eroding upstream.

Where the channel width at the structure site is limited, the box type inlet is the most suitable.

These structures can be built either by farm labor or by contractors. Rubble masonry or concrete block structures have been made with farm labor while the reinforced concrete work usually requires the services of a contractor.

1. GENERAL (CONT'D)

FIGURE 12.2

Within the last few years manufacturers have developed interlocking, or wrinkled, steel sheet piling that is suitable for small structures. This material is now being used for weir notch spillways and is working very satisfactorily. The piling can be driven into position or dug in and bolted together and the notch cut to the proper dimensions with an acetylene torch.

For low heads and small quantities of water, all of these structures provide excellent control at reasonable costs. For peak discharges of 100 to 250 c.f.s. the weir notch type is more economical than the box type which is used to carry the larger capacities.

Principal or Drop Inlet Spillway

Principal spillways of metal or concrete in earth dams are more adaptable for high heads (ten feet or more). Drop inlets can be used to increase the flow through a low head structure, such as a road culvert. This type of structure is well adapted to sites which provide an appreciable amount of temporary storage above the inlet.

1. GENERAL (CONT'D)

Figure 12.3

Principal or drop inlet spillways are used for:

(1) Outlets for stock water dams or water storage reservoirs to reduce the trickle flow over the vegetated spillway.
(2) Erosion control structures to halt eroding gully heads.
(3) Correcting overfalls adjacent to streambanks.
(4) Outlets for detention dams or settling basins to control flooding and siltation of lower-lying lands.
(5) Roadway structures.

1. GENERAL (CONT'D)

FIGURE 12.4

For high heads, this type of construction requires less material than a weir notch or box type drop spillway under similar circumstances and capacity requirements. Earthfill costs on drop inlets may be quite high but may be less than concrete drop spillway costs, so the total price is less. Dams with a principal spillway are relatively easy to build and may be constructed by either farm labor or contractors.

Chute Spillways (Formless)

Chute spillways constructed without forming are sometimes used in terrace outlets where the head control is low and spillway capacities are quite small (20 to 120 c.f.s.). Their use is limited to areas where temperature variations are moderate. Reinforcing should be used where extreme variations in temperature are expected. These spillways are easy to construct. In some cases reinforced concrete blocks are used as side walls.

These structures are used at the ends of terraces or in outlets and waterways. Some are constructed to control small overfalls in fence lines.

This type of spillway cannot be used as a water-impounding structure nor is the life expectancy as long as other permanent structures.

1. GENERAL (CONT'D)

Chute Spillways (formless) (cont'd)

The costs are low since form work is eliminated, cutoff walls, etc., are minimized, and inexperienced labor can do all of the work.

Concrete high velocity chutes have also been constructed in the middle of grassed waterways to reduce secondary cutting and carry most of the runoff from small rains. Here again, reinforcing must be used when the temperature variations are considerable. On these structures the inlet must be properly designed so the center section will carry maximum flow without creating erosion along the edge of the concrete. The velocity of the flowing water becomes very high on the steeper slopes.

Figure 12.5

The outlet must also be designed to dissipate the energy of the water and prevent downstream erosion.

These high velocity chutes can be designed for small flows or to carry flows up to 50 or 75 c.f.s. but the construction costs increase proportionately according to the structure's capacities.

1. GENERAL (CONT'D)

Chute Spillways (formed)

Formed side walls, wing walls, cutoff walls, etc., are needed on chutes having high heads and where high discharge capacities are required. Gully heads in drainageways and overfalls in streambanks are the usual kinds of conditions requiring control by these structures. The wing walls and earth embankment direct the water into the sloping portion of the chute. The large capacities and drop in these structures necessitates a large outlet apron and energy-dissipating blocks or barriers. Debris will rarely clog a structure of this type.

For a fall of ten feet or less, drop spillways may cost less because they do not have the elaborate inlet and outlet required for chute spillways. A dry site is best for construction, as unstable soils or seepy banks require expensive under-drainage systems.

FIGURE 12.6

The form work and precision required in the construction of formed chute spillways are usually best accomplished by a contractor. Costs are quite high, but the structure is relatively economical for high heads and large discharge capacities.

1. GENERAL (CONT'D)

Irrigation Drops

Small irrigation structures in farm mains or laterals may drop the water only 1 to 3 feet and handle 1 to 4 c.f.s. The principles of design are essentially the same as for large structures which have been constructed in irrigation district systems to handle larger flows over greater drops. Some treated wood structures have been used, but their life expectancy is short and they require constant maintenance. Concrete structures may use form work for the wing and side walls, with the apron troweled. Reinforced concrete blocks have been used, as well as small drop inlet structures of pipe and earth. All of these will step down the water and reduce flow line grades.

FIGURE 12.7

Costs may seem high to the irrigator, but the efficiency of these structures in controlling the water flow makes the expenditure worth while.

2. SURVEYS

A thorough field survey should be made of site locations for these structures so that the most economical type of structure can be designed. Profile and cross sectional surveys are needed to show the characteristics of the waterway above and below the structure. The structure may affect the flow of water for quite a distance above and below its proposed site, or have an effect on other structures. Topographical information may also be needed on the structure site itself for detailed designing. Decisions on these surveys must be made in the field and based on the type of structure being considered. Other parts of this handbook will give the degree or amount of survey information needed.

The field surveys should also give the location and sizes of various bridges, culverts, fence lines, buildings, etc., - any of which may influence the design of the structure. Determinations must be made as to the size and shape of the watershed and all other factors that will influence the runoff and the design of the structure.

An effective and permanent grade stabilization structure must have a stable downstream grade. If one structure does not do this, then additional structures may be needed. A stable grade exists when the channel is neither aggrading nor degrading.

The site selection will be influenced to some extent by the availability of materials. If a drop inlet structure is being considered, suitable core and fill material should be readily available, or the cost of the structure will rapidly mount. A supply of rocks suitable for a rubble masonry structure may be the deciding factor on the type of drop spillway to construct.

The type of foundation for any proposed site may determine the type and size of structure to be constructed. Wet, seepy foundations are not suitable for large concrete structures unless the design includes expensive corrective measures. This may be the place where a drop inlet with a deep core wall is needed. Dry, unstratified foundations are suitable for almost any type of structure. Where there are wet areas on the structure site, drop spillways or cutes can be constructed in the drier areas and the waterflow diverted to them.

When the structure is for the control of the gully head or overfall, the site selection must be carefully made. The lip of any erosion control structure should be set at an elevation which anticipates the upstream movement of the gully head.

The location for the suitable emergency spillway is another important factor in selecting a site for any erosion control, detention, or stockwater dam where part of the flow is carried through the dam by a tube. In some cases, drop spillways or chutes will need an emergency spillway to help carry the larger flows around the end of the embankment. Therefore, a field investigation for site locations must include a full consideration of this important part of these structures. Profiles and cross-sectional

2. SURVEYS (CONT'D)

surveys of the proposed spillway sites may be needed for a design that includes adequate capacities at non-erosive velocities.

The peak and volume of runoff is almost directly proportional to the length and size of the watershed. The site chosen for a structure may be adapted to a drop spillway, but the drainage area and subsequent runoff may be too large for this type of grade stabilization structure. For large runoff volumes or high peak flows, temporary storage may be required to provide an economical discharge. Field investigators must consider the need for temporary storage at the time that a preliminary site selection is made.

Consideration must be given to the land use at the proposed site, or immediately adjacent to it. Drop spillways or chutes may be placed in cropland since they do not have water storage incorporated into the design which would be lost by siltation. Improper land use adjacent to or at the structure site may seriously reduce the effectiveness of the structure or downstream stable grade. At least 75% of the land treatment measures and proper land use should be applied to the watershed when siltation would seriously affect the life and efficiency of the structure.

3. DESIGN

Part 5 of this handbook covers the design and construction of outlets and waterways as grade stabilization measures. When secondary cutting occurs it can only mean one of two things: (1) that the size, shape, and grade were incorrectly designed, or (2) proper maintenance was not performed.

Additional information on drop spillways and cutes is covered in Part 15 of the handbook, with principal spillway design and construction outlined in Part 9. The National Engineering Handbook, Sections 11 and 14, gives additional detailed design information.

Rule of thumb estimates have been used to indicate what a stable grade might be - such as 0.5% or 0.5 foot per 100 feet of channel. This assumption may be accurate enough for small structures, but the design of larger capacity structures should be based on a more complete analysis of the situation. It was mentioned earlier that a stable grade for a channel is one in which there is neither aggradation or degradation. When the design inflow or outflow of a structure is determined, these quantities must be routed through the channels above or below the structure. If the waterflow is at an erosive velocity, the grade may have to be lessened or the project costs include changes in the channel size or shape. The choice can be made by additional hydraulic calculations for flow through open channels. If the waterflow is too slow, the formation of meanders or silt bars will be encouraged, and a revision of the channel hydraulic characteristics should be considered. It is important that the field engineers give technical guidance on this point.

3. DESIGN (CONT'D)

It must be remembered that continuous flows of clear water are more erosive to channel banks than intermittent flows or water carrying colloidal materials. Also, that the introduction of a structure in a gully may cut off much of the silt load that normally passes downstream.

A stable grade for sandy or gravelly soils will not be the same as for heavy clay soils even when all other things, such as volume of water, velocity, size of channel, etc., are equal. Channels for carrying a flow of water should be shaped so the sides and/or bottom can be revegetated or sodded with suitable grasses. The cross section of the channel should provide for a uniform distribution of flow throughout its entire length. Transition sections should be provided at all breaks in grades, and abrupt turns avoided.

On overfall type structures, scour at the outlet is one of the important factors leading to a structural failure. Scour may be controlled by giving proper consideration in the design to (1) stability of the grade below the structure, (2) velocities occuring in the downstream channel, (3) tail water elevations for different flow stages, and (4) dissipation of water energy in the outlet. High tail water elevations may reduce scour below drop spillways or chutes. Scour on drop inlets is reduced by having the pipe section extend beyond the toe of the fill and cantilevered on a pipe support to overcome undercutting of the pipe.

4. LAYOUT

Other parts of this handbook describe the necessary surveys for setting line and grade stakes for construction of the various structures.

5. CONSTRUCTION

Any overfall above an erosion control structure should be sloped to allow water to enter the pool area without additional erosion even though the inlet crest may be the same as the gully head elevation.

Channels below the structures should be shaped when the structure is built. Large irregular banks standing below an intrenched drop spillway will not erode to the desired shape for the outlet channel without creating undesirable bank slopes and silt bars downstream.

CONTENTS

PART 13

STREAM BANK PROTECTION

Subject	Page
1. General	13-1
2. Investigations	13-1
3. Types of Protection	13-2
4. Treatment	13-2
Vegetation	13-2
Jetted Willow Poles for Bank Protection	13-2
Blanket Protection with Large Trees	13-2
Piling Revetment with Wire Facing	13-4
Streambank Control with Jacks	13-7
Deflector Jetties	13-7
Rock and Willow Jetties	13-8
Piling Deflecting Jetty	13-12
Tree or Log Jetties	13-12
Wire Bound Rock Jetties	13-14
Brush Mat Riprap	13-14
Rock Riprap	13-14
5. Maintenance	13-18

LIST OF FIGURES

PART 13

STREAM BANK PROTECTION

Figure No.	Title	Page
13.1	Jetted Willow Poles	13-3
13.2	Tree Jetty	13-5
13.3	Piling Revetment with Wire Facing	13-6
13.4	Detail of "Jack"	13-9
13.5	Streambank Control with "Jacks"	13-10
13.6	Method of Locating Jetties	13-11
13.7	Rock and Willow Deflection Jetty	13-13
13.8	Piling Deflecting Jetty	13-15
13.9	Tree Jetty	13-16
13.10	Rock Wire-Bound Sausage Type Jetty	13-17
13.11	Brush Mat Revetment	13-19
13.12	Dumped Rock Riprap	13-21

PART 13

STREAM BANK PROTECTION

1. GENERAL

Stream bank erosion is a geologic process that is constantly shifting and sorting the alluvial fill in stream valleys. Sedimentation due to upstream erosion, channel blocks and restrictions such as bridges, diversion dams and snags causes increased stream meandering that aggravates bank erosion. Most of the bank erosion is caused by flood stages. The major part of the erosion occurring during any one flood occurs after the peak has been reached. As the stream subsides after reaching peak flow stage, there is movement of underground water, known as return flow, from the valley to the channel. The differential in pressure creates a force that tends to develop sloughing of banks. There are locations in the state where bank cutting is damaging or destroying valuable cropland, endangering farmsteads, bridges and roads, and creating high maintenance costs in connection with public utilities. Property values may be high enough at these locations to enable landowners or corporations to take steps to provide local protection. Work unit personnel should not attempt such work without special engineering assistance, except for the simpler jobs on small streams.

2. INVESTIGATIONS

The behavior of streams at flood stage or near flood stage is often unpredictable without detailed study. This makes it advisable to avoid jobs of large size unless good engineering assistance is available.

Before treatment of any stream bank is started, the following items should be considered:

1. Size of watershed draining into the stream.
2. Expected flood peaks.
3. Expected debris load carried by the stream.
4. Causes of existing meandering and erosion.

Included among them may be such things as fallen trees deflecting water from its normal direction of flow, trees or brush growing on the inside of a course deflecting water against the cutting bank, water from a smaller stream entering the channel and depositing sediment, thus deflecting the water against the cutting bank.

The flow line of a stream is often the property boundary between adjacent owners. Care must be taken not to divert a stream from its natural channel; the ultimate result may be to trespass on another man's property.

The economic soundness of any project should be determined at the very outset. The cost and damages of the control should be weighed against the resulting benefits.

3. TYPES OF PROTECTION

There are two general classes of bank protection:

1. Those which retard flow along the bank and thereby promote deposition.

2. Those which, through some form of bank cover, protect the bank from direct erosion and scouring.

Permeable jetties constructed of piling, rock, tetrahedrons, trees or other materials are examples of protection causing deposition. Jetties may either be designed to deflect the current away from the bank or they may be placed parallel to the bank and designed to reduce the velocity of flow adjacent to the bank to the degree that erosion will be halted. Living vegetation, brush matting, rock riprap, concrete slabs and asphalt lining are examples of protective bank cover. The type of protection needed for a specific case is largely determined by the characteristics of the stream.

4. TREATMENT

Vegetation

Vegetation plays an important part in the control of bank erosion. It may be used alone on small streams, or it may be used in conjunction with mechanical measures. There are two problems in using vegetation alone for protection.

1. Getting the stand established.
2. Stabilization of that section of the bank below normal water surface so that vegetation will not be undercut and the bank slough into the stream.

Vegetation is used most successfully above the waterline on properly sloped banks and on the flood plain adjacent to the banks to retard velocity. Vegetation should always be used back of revetments and jetties in the area where silt deposition occurs and on slopes protected by brush mats.

Jetted Willow Poles for Bank Protection

Drive or jet in willow poles on the cutting side only at or just above the normal waterline in a double row with the poles two to four feet apart and staggered between rows (Figure 13.1). The poles should be six to nine feet long, three to five inches in diameter, and should be cut from willows if available. About two-thirds of the pole should be below the ground line. Supplement with plantings of willow cuttings or plants. This type of protection is adapted to the smaller streams where ice damage will not be a problem.

Blanket Protection with Large Trees

A pervious revetment made from whole trees cabled together and

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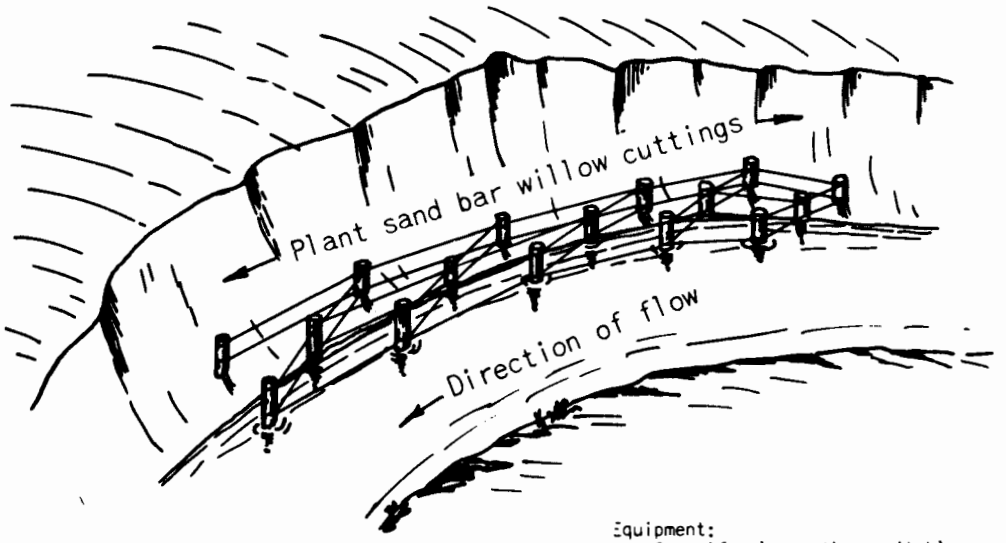
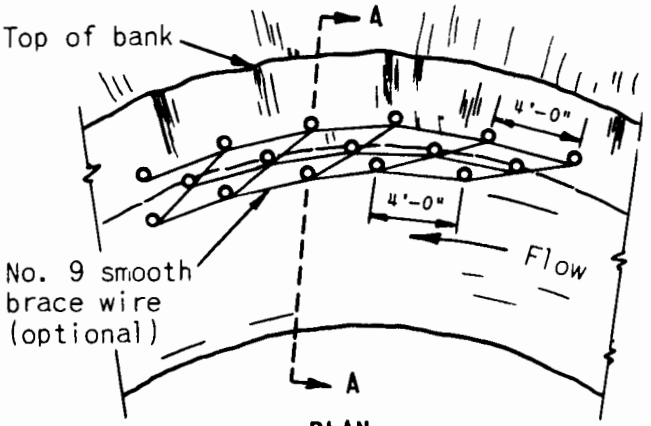




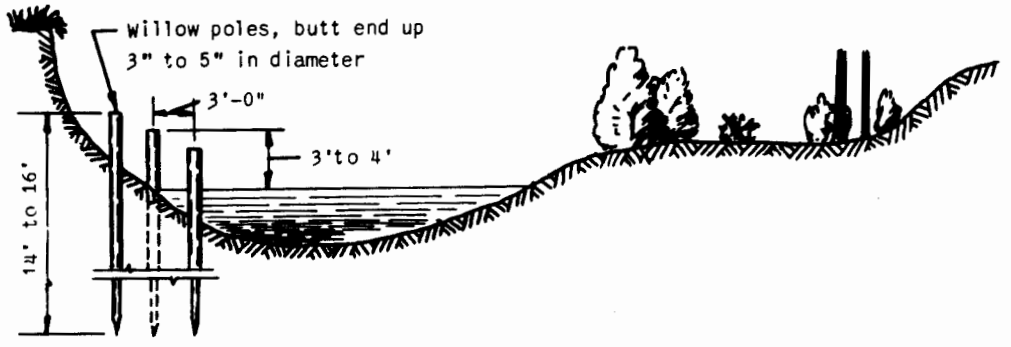
PLAN
Not to scale

Equipment:
Centrifugal or other suitable pump, 150 G.P.M., (10' head), 2" discharge, 45' discharge hose, 15' inlet hose and 6' of 1 1/4" pipe for a jet.

Method:
Prepare a hole with jet pipe and hose by working the jet up and down to a depth of 10' to 12'. Leave jet in for half minute or so to be sure enough sand has been displaced to allow easy placing of pole. After the pole has been placed it should be secured by shoving the jet in a few times at an angle near the top of the hole. Use two rows of poles on long curves and four or five rows in sharp bends. Sand bar willow cuttings should be planted to form a living revetment. Protect against livestock until willows or other applicable species are established.

Application.
This method is used in the smaller streams where there is no heavy ice or debris load and where the stream bed is sand or fine gravel.

Performance:
In a typical job, 800 feet long, 15 man days were used to cut and jet poles and tie the brace wires; jet pump was operated a total of 9 hours.



SECTION A-A
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Figure 13.1 JETTED WILLOW POLES

4. TREATMENT (CONT'D)

Blanket Protection with Large Trees (cont'd)
anchored by deadmen buried in the bank is probably the cheapest form of semi-permanent protection, at least as regards cost of material. Trees having a trunk diameter of 12 inches and larger are required to provide a good barrier. Cottonwoods are the best type as they grow to sufficient size and have a brushy top. The trees are laid along the bank with the butts upstream. Enough overlap should be provided to insure a continuous protection to the bank. The trunks are anchored to deadmen set in the bank by means of cable. Piling can be used in lieu of deadmen providing they can be driven well below the point of maximum bed scour. It is very important that trees be securely anchored as they could do severe damage to bridges or other structures if they should break free during a flood. The rapidity with which silting occurs depends on the amount of sediment transported by the streams. Trees have a limited life and must be replaced periodically. In streams where heavy ice flows occur, considerable damage to the trees will be encountered. Loss of trees through damage or deterioration will again expose the bank to the current and it will continue to undercut and erode. The stability of the bank above the normal water level can be increased by planting trees and shrubs. Planting should be delayed until the trees have silted in and deposits commence to form back of them. This type of protection is not adapted to narrow streams where channel width will be materially reduced by placement of trees. It is well adapted where the water at the toe of the slope is deep. A typical plan of a tree revetment is shown in Figure 13.2.

Piling Revetment with Wire Facing.

Continuous piling revetment with a facing of woven wire is a very common type of protection. It is particularly adapted to streams where the depth of water next to the bank is in excess of 3 to 4 feet. It has an advantage over riprap and brush mat construction in deep water as it is more economical and eliminates the problems involved in building a stable foundation under water for holding the riprap in place. This type of protection is easily damaged by ice flows or heavy flood debris and should not be used where these problems occur. The piles are spaced from 6 to 8 feet on centers. Timber piles should have a diameter sufficiently large to permit driving to the required depth. Railroad rails may be used when available. The pilings are driven to a depth of approximately one-half length below the point of maximum scour. If the stream bed is firm and not subject to appreciable scour, the pile should be driven to refusal or to a depth of at least one-half the length. The pilings are carried to the height required to protect the bank which may be the full height or a lesser height if it is practical to use vegetation or other types above a certain elevation.

A heavy grade of woven wire is fastened to the stream side of the pile. Its purpose is to collect debris and trash and form a permeable wall which serves to reduce the velocity on the bank side. If the stream bed is subject to scour, the wire is extended horizontally along the stream bed at a distance equal to the anticipated scour. Concrete blocks or other weights are attached to the ends at regular intervals. During floods when scour occurs the weights cause the wire to settle in a vertical position along

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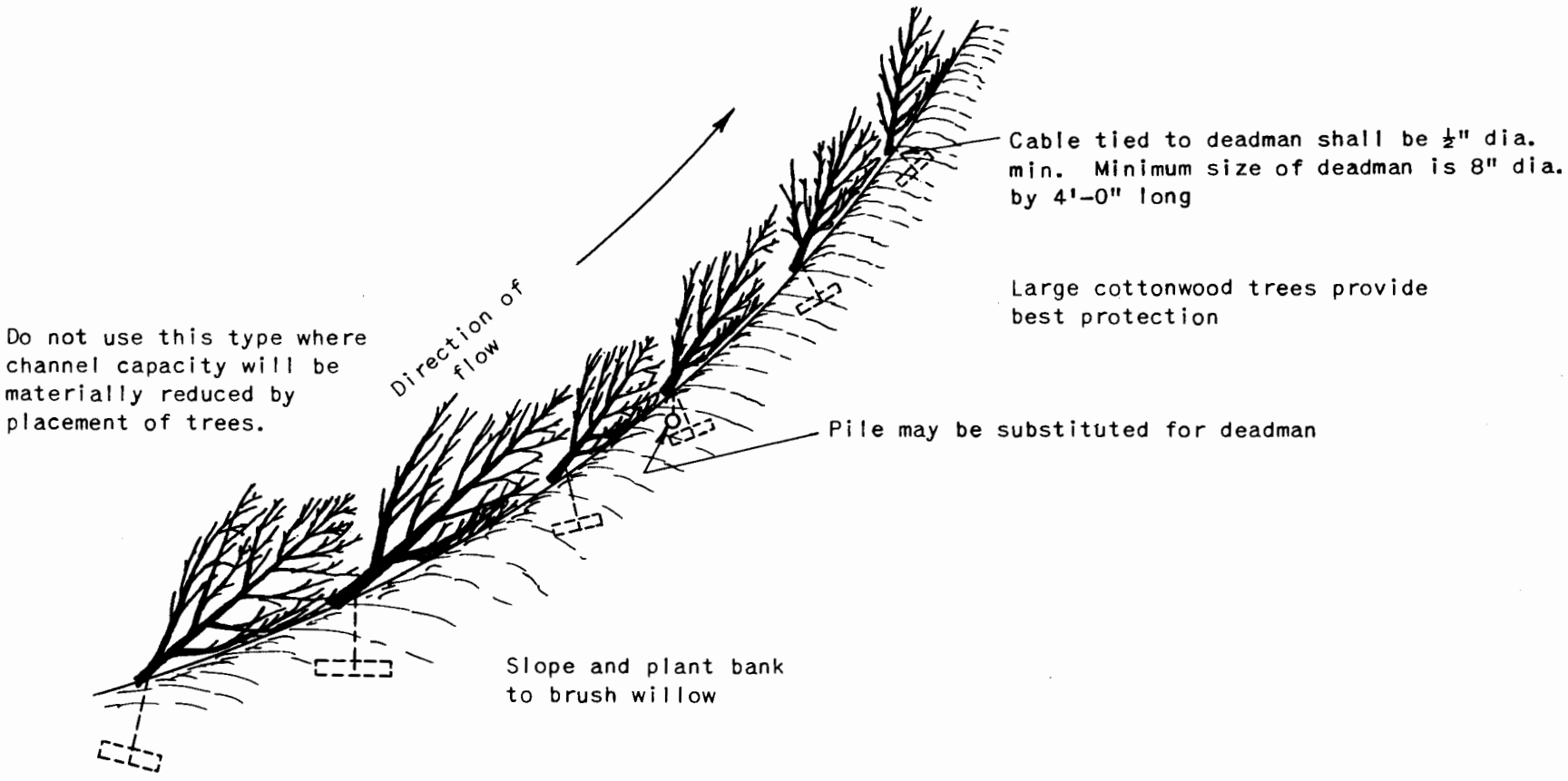
Cable tied to deadman shall be ½" dia. min. Minimum size of deadman is 8" dia. by 4'–0" long
Large cottonwood trees provide best protection
Do not use this type where channel capacity will be materially reduced by placement of trees.
Direction of flow
Pile may be substituted for deadman
Slope and plant bank to brush willow

Figure 13.2 TREE JETTY

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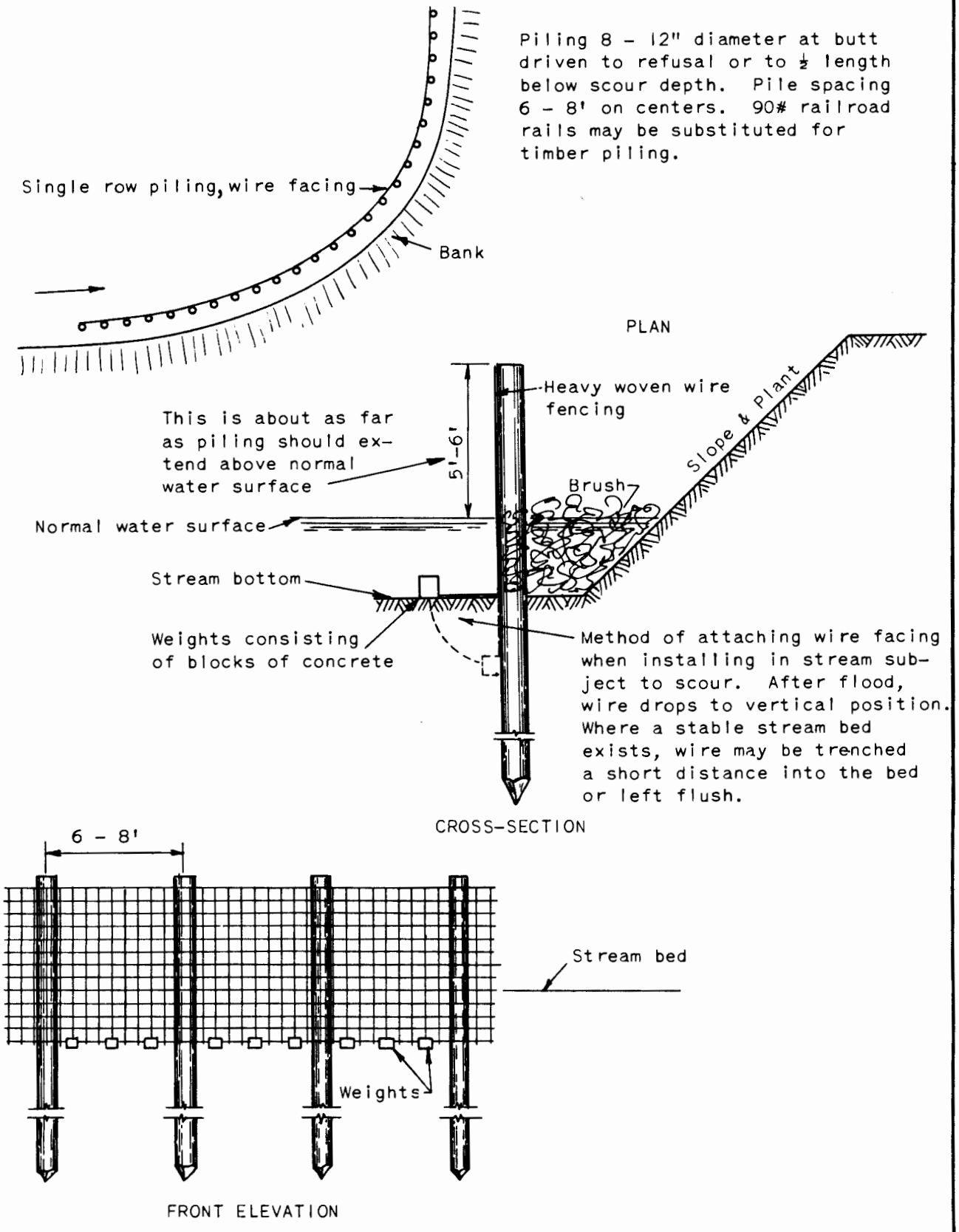
Piling 8 - 12" diameter at butt driven to refusal or to ½ length below scour depth. Pile spacing 6 - 8' on centers. 90# railroad rails may be substituted for timber piling.
Single row piling, wire facing
Bank
PLAN
Heavy woven wire fencing
This is about as far as piling should extend above normal water surface
5'-6'
Slope & Plant
Brush
Normal water surface
Stream bottom
Weights consisting of blocks of concrete
Method of attaching wire facing when installing in stream subject to scour. After flood, wire drops to vertical position. Where a stable stream bed exists, wire may be trenched a short distance into the bed or left flush.
CROSS-SECTION
6 - 8'
Stream bed
Weights
FRONT ELEVATION

Figure 13.3 PILING REVETMENT WITH WIRE FACING

4. TREATMENT (CONT'D)

Piling Revetment with Wire Facing (cont'd)
the face of the pile. The piling can be strengthened considerably by connecting the tops with waling or by installing a system of cross-bracing. Placing brush and debris back of the piling will increase effectiveness. Where piling revetment extends for several hundred feet a few permeable dams constructed of brush or brush and rock placed at right angles to the revetment will tend to stop currents developing between the bank and the piling. Typical details of a piling revetment are shown in Figure 13.3.

A more expensive type of construction which gives more protection is built by using two rows of piling having rock and brush in between. The rock and brush are placed in wire baskets which must be set in a trench excavated to at least one-half or more of the depth of the anticipated scour. If the blanket settles the wire may be extended and additional material added to keep the brush and rock level with the top of the pile.

Streambank Control with Jacks.

A method of streambank control which can be used rather easily by farmers or ranchers consists of placing one or more rows of jacks along the streambank. These "jacks" are constructed by cutting three poles 10 to 16 feet in length, depending on the depth of the stream which is to be controlled. (Multiply depth of stream by 1.4 to determine length of poles required.) These are crossed and wired together at the mid-points. The ends are then tied together with No. 9 wire, as shown in Figure 13.4. The next step is to place the jack in the stream. A series consisting of enough to protect the area where cutting occurs should be constructed. They should be spaced as close together as possible, with not over one jack space apart. This will provide an almost continuous line of revetment. (See Figure 13.5). The jacks are held in place by tying the center of the jack with cable clamps to a main cable which is carried around through the center of the jacks on the area to be protected. The upper and lower end of this cable is tied to a deadman which in turn anchors all the jacks as a unit. The cable should be 1/2" to 3/4" depending on length protected and depth of stream. The deadman should consist of about a 6' timber about 8" to 10" in diameter. Each jack should be weighted by rock which can be wired onto the poles.

If permanence is desired and vegetation will not furnish the ultimate control, angle irons or reinforced concrete posts can be substituted for the poles in the jacks as mentioned above. Also some steel fabrication plants make them for sale on a contract basis.

Deflector Jetties.

Deflector jetties serve to deflect the current away from the bank. They may be built of large stone, wire-bound rock baskets, rock and brush, trees or piling. The location, number and spacing of jetties are determined mainly by the direction of the stream current and the curvature of the bank.

4. TREATMENT (CONT'D)

Deflector Jetties (cont'd)

Jetties are particularly useful where water adjacent to the bank is more than 4 feet deep and where the velocity of the water is too high to assure protection with anchored trees.

The general rule for spacing of jetties is shown in Figure 13.6. The angle at which jetties are placed with the bank, or line formed by the low water elevation, varies from 30° to 45° . As will be seen by the sketch, the length of the jetties has a direct bearing on the spacing. The length for any one location is a matter of judgment. As a system of deflector jetties reduces the channel section available for passage of floods, they must not extend out in the stream far enough to reduce the channel capacity appreciably. This factor is particularly important on small streams deeply recessed in the valley floors having limited channel capacity.

Studies of models and observations in the field indicate that there is a limiting degree of curvature at which jetties are economical. Since the spacing of jetties in a properly designed jetty system decreases with sharpness of bank curvature, a point is reached where more material would be required for jetties than for some type of continuous structure. Also, as the flood stage rises, the current may shift its direction on sharp curves and strike the bank between jetties, thereby reducing their effectiveness. For bank curvatures exceeding 30° , or a radius less than 200 feet, it is safer and more economical to use some type of continuous protection.

If the opposite side of a stream consists of a high bank which cannot function as a floodplain, there is little chance of the protective work being successful. In other words, do not attempt streambank protection with jetties between opposite high banks where velocities cannot be reduced by spreading of the flood waters.

Rock and Willow Jetties

Figure 13.7. Tie willows into bundles. Willows composing a bundle should be as nearly uniform in length as possible. Tie at two places with No. 9 black annealed wire (long bundles should be tied in three places). If each bundle is tied at the same relative position the subsequent operation of tying the bundles together to form an integral mat will be facilitated. Willows can be tied into tight bundles quickly by using a device similar to the one described as follows:

> Two or three sawhorses spaced six to ten feet apart are tied together with longitudinal stringers. Fastened to the top of each sawhorse is a 2" x 6" which has been shaped to leave a curved surface (concave upward) on which the willows are laid for bundling. When enough willows to make a twelve to eighteen inch diameter bundle have been placed on the rack they are tied tightly together with No. 9 wire

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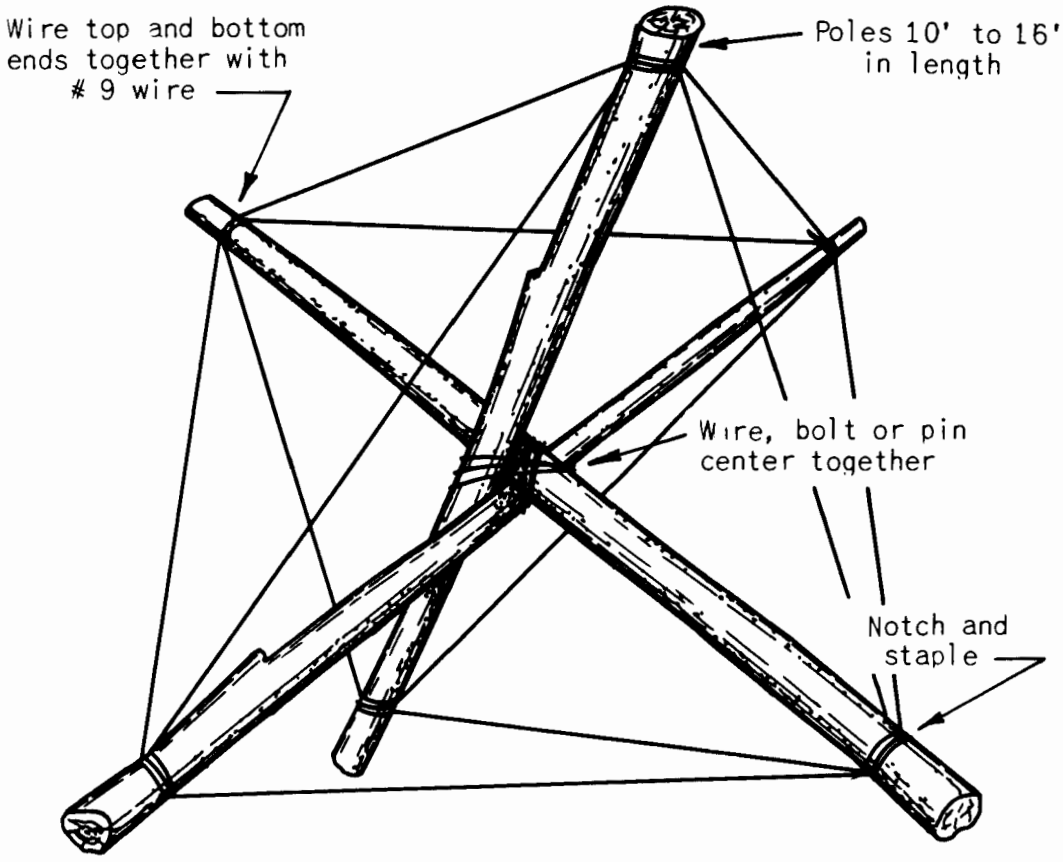

For streams of high velocity a more sturdy construction would be to tie all ends together.

Figure 13.4 DETAIL OF "JACK"

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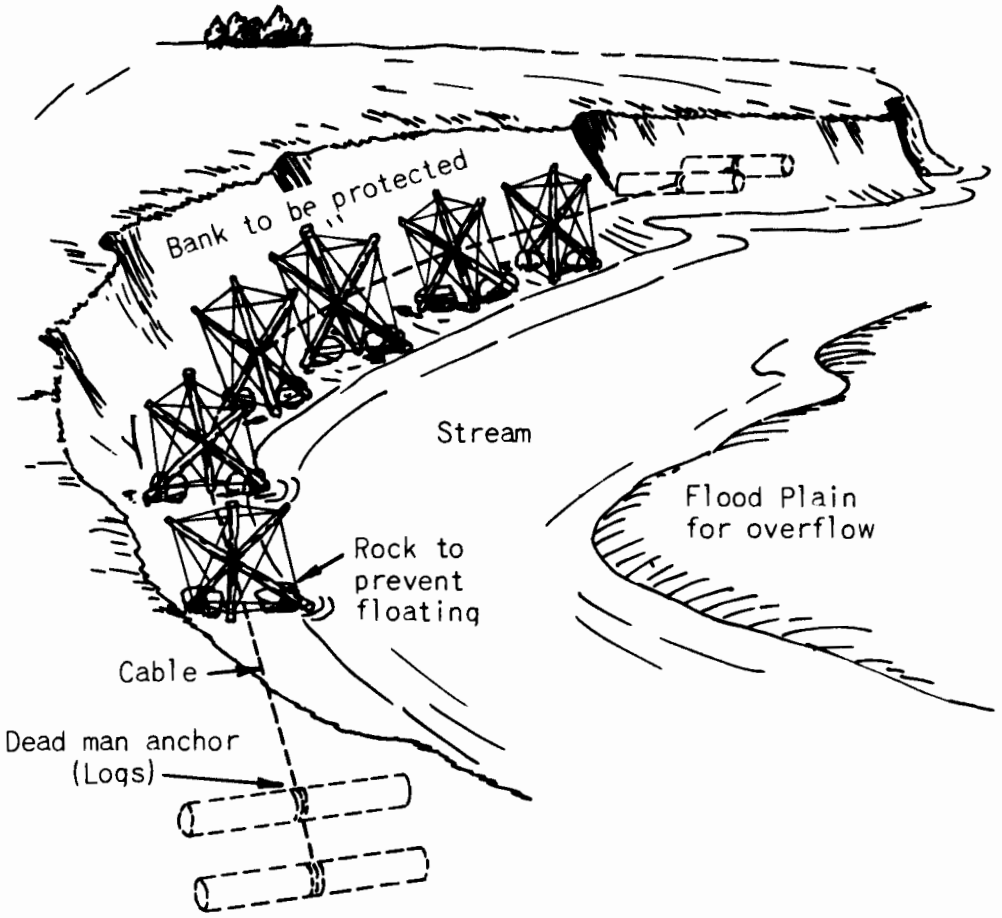

Figure 13.5 STREAMBANK CONTROL WITH "JACKS"

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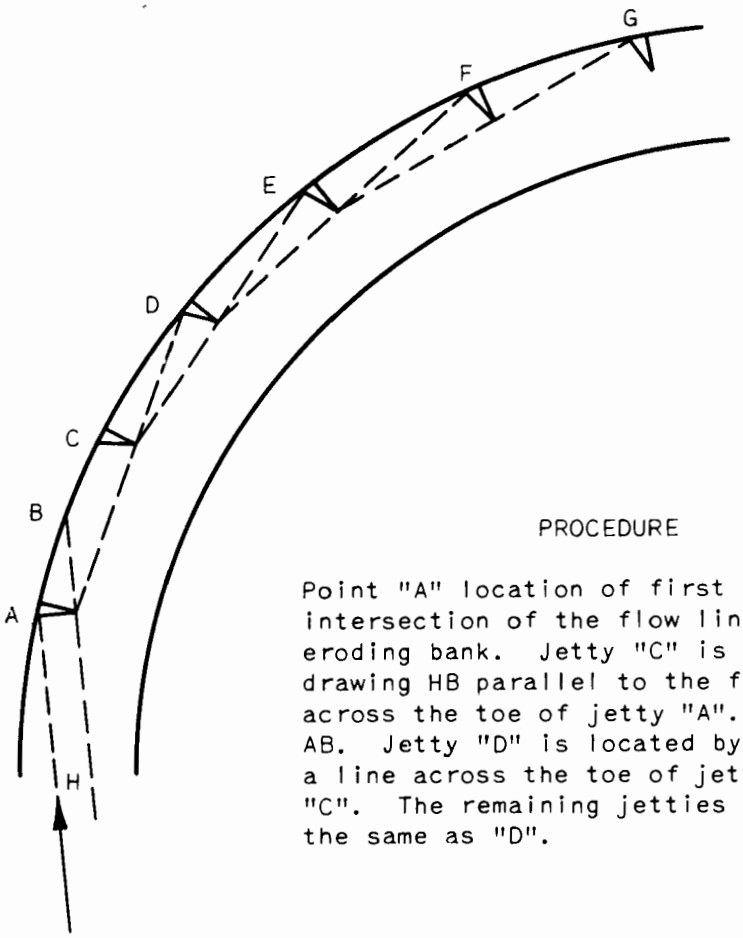

PROCEDURE

Point "A" location of first jetty is the intersection of the flow line and the eroding bank. Jetty "C" is located by drawing HB parallel to the flow line and across the toe of jetty "A". AC is twice AB. Jetty "D" is located by projecting a line across the toe of jetties "A" and "C". The remaining jetties are located the same as "D".

Figure 13.6 METHOD OF LOCATING JETTIES

4. TREATMENT (CONT'D)

Rock and Willow Jetties (cont'd).

while the willows are being compressed by means of a double lever device consisting of two 1" x 2" hardwood sticks connected at one end of each with a short piece of suitable rope or cable. (One stick is passed under and around the bundle, then crossed with the other stick and when pressure is applied to the ends of the sticks, the rope on the upper side and the crossed sticks on the sides and top serve to compress the bundle.)

At the location selected for the deflecting jetty, the bank should be sloped for a "transition section" at least 1:1 for a distance of ten to fifteen feet upstream from the point where the jetty will swing away from the bank into the stream.

Beginning at the upper end of the transition section, lay the willow bundles closely together with the butt end up working the tips into the stream bed. Tie each bundle to the adjacent bundle to form an integral mat. (Occasionally it will be necessary to place a bundle or two with the butt ends down to avoid a "fan" effect.) The portion of the jetty extending into the stream must be higher on the bank side as indicated in Section C-C, Fig. 13.7. In order to obtain this condition place a wedge-shaped pile of rocks in the stream bed with the higher portion of the wedge underneath the butt ends of the initial willow mat layer. The top of the mat is then covered with rock, with the heaviest rock placed near the butt ends to resist displacement by the high water velocities. Successive layers of willow mat and rock are added, until the desired height is obtained. Be sure to work the tips of the willows into the stream bed. When unusually high velocities are encountered it is advisable to place a layer of hog wire on the bed on the stream under the initial rock and willow layer, bringing the wire around to the tip of the jetty, up and over the top of the mat and fastened to it.

The mat should be bank high at the junction with the bank. The jetty should slope toward the downstream end to produce the desired effect of deflecting the stream away from the eroding bank and depositing silt behind the jetty.

Piling Deflecting Jetty.

The upper end of the piling jetty is constructed the same as the rock and willow jetty. Piling is then driven or jetted as indicated in Figure 13.8. This type of jetty is not adapted to conditions where heavy ice flows will occur.

Tree or Log Jetties

Tree or log jetties are constructed by excavating a trench into the bank and driving two pilings on either side of the trench near the water line, Figure 13.9. Two cables are then laid across the trench and the trees or logs placed in the trench. After sufficient trees have been placed in the trench the cables near each end are then bound around the trees to tie the jetty together. A cable is also tied between the piling

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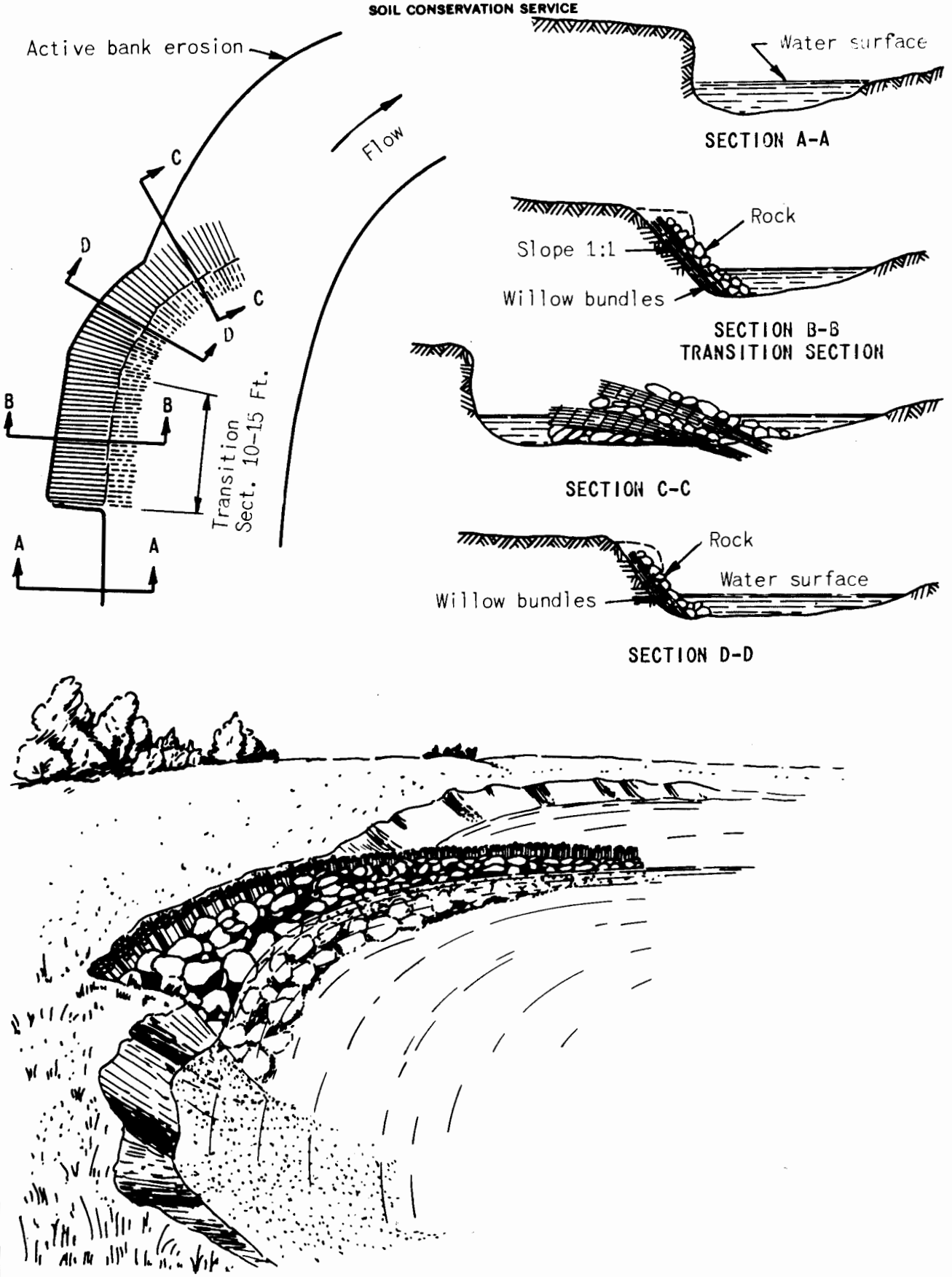

Figure 13.7 ROCK AND WILLOW DEFLECTION JETTY

4. TREATMENT (CONT'D)

Tree or Log Jetties (cont'd)
across the top of the jetty to hold the trees down during high water. The tree or log jetty should slope toward the downstream end to produce the desired effect. Backfill the trench excavated in the bank to natural ground elevation after the jetty is complete. This type of jetty is not easily damaged by ice when the trees are tightly bound together.

Wire Bound Rock Jetties.

Wire bound rock jetties are constructed as indicated in Figure 13.10.

Brush Mat Riprap

Brush mats with shrub plantings protected at the toe with rock riprap will give very good results. This is an expensive type of construction due to the hand labor involved. As a brush mat has a short life, its main value is to afford a mulch that will permit a dense growth of vegetation to take over. It is only practical at locations where willow brush and rock are readily available in quantities sufficient to meet the need of the job. The construction procedure is to place the rock toe using it as a base for the brush mat. The rock toe should be carried to the low point of the channel and be at least 18 inches in thickness to remove the danger of displacement during flood flows. It is not practical to use a rock toe in streams subject to channel scour as it is usually not feasible to place enough rock to compensate for the loss due to downward movement created by the temporary deeping of the channel. The sloped banks should be planted before the brush matting is applied. The best time to plant is in the spring. It is difficult to secure a reasonable stand when planting new cuttings through a mat.

The brush should be placed over the exposed soil as soon as possible after the bank is planted. Bush willow affords the best material. The brush is laid shingle fashion with the butts pointing up the bank. The brush should be straight enough to lie flat on the bank. The mat should be 6 to 18 inches thick, depending on the size of the stream and the ice hazard. The mat is held in place by driving stakes at an angle crossing each other in pairs or by stakes driven straight into the ground about 2'-6" on centers and interlacing with galvanized wire. After the wire is attached the stakes are driven deeper which tightens the wire and binds the mat firmly. Stakes driven at an angle and crossed in pairs are only adaptable to small streams. The details of a brush mat riprap are shown in Figure 13.11.

Rock Riprap.

Rock riprap is one of the most effective methods of stream bank erosion protection. It is costly because of the difficulty of quarrying, transporting and placing the stone and the large quantities needed, particularly where streams are deep. For successful riprapping the toe of the

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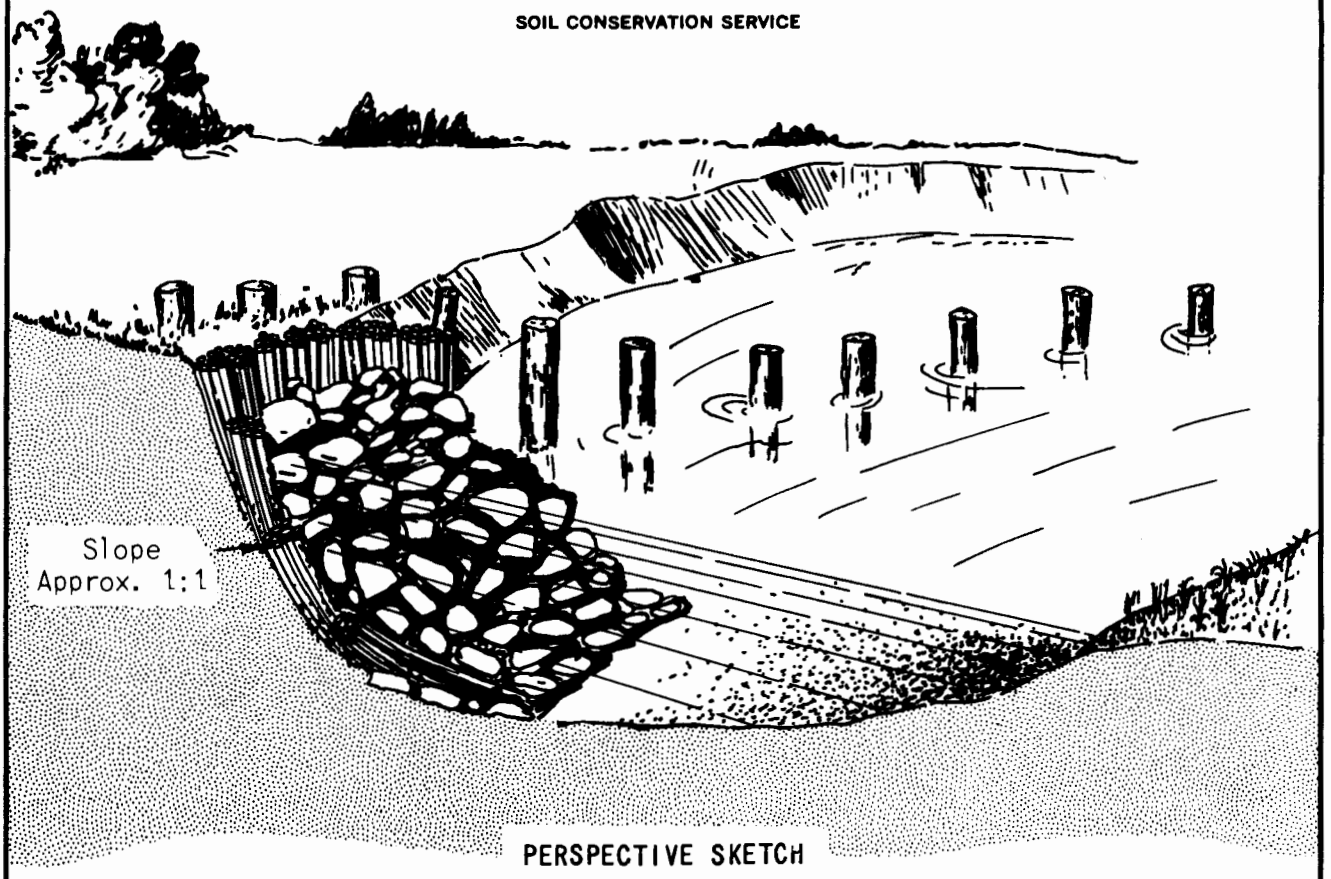

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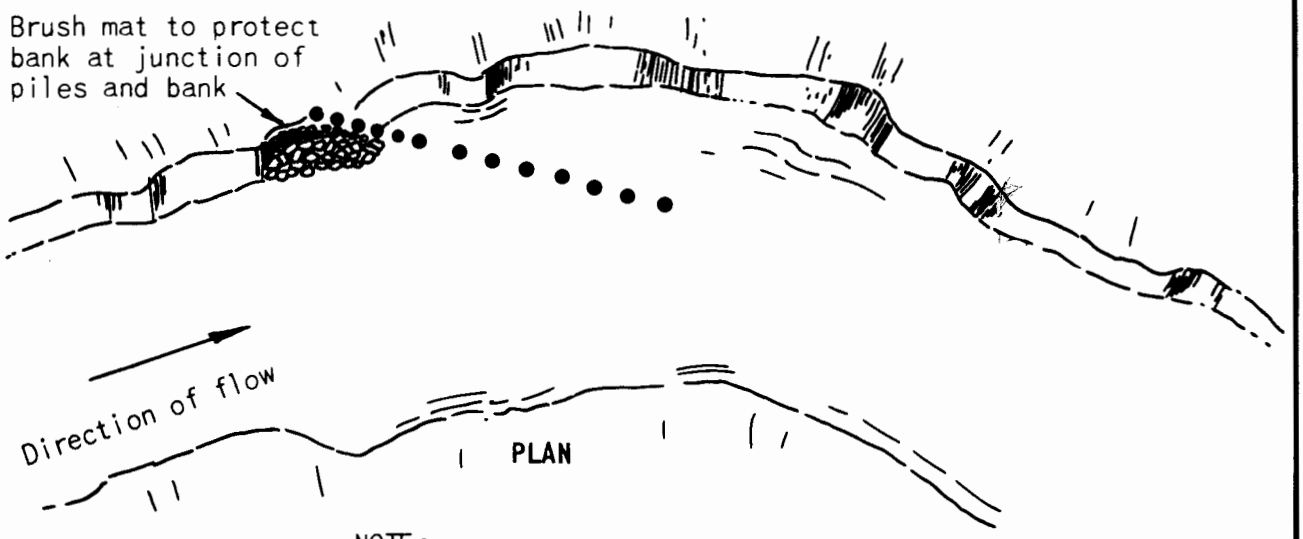

PLAN

NOTE:
Space piles 1'-6" min. out approx. 6'-0" from bank, then 3'-0" min. the balance of the way out in the stream.

Piles to be driven to 1/2 to 2/3 of their total length.

Figure 13.8 PILING DEFLECTING JETTY

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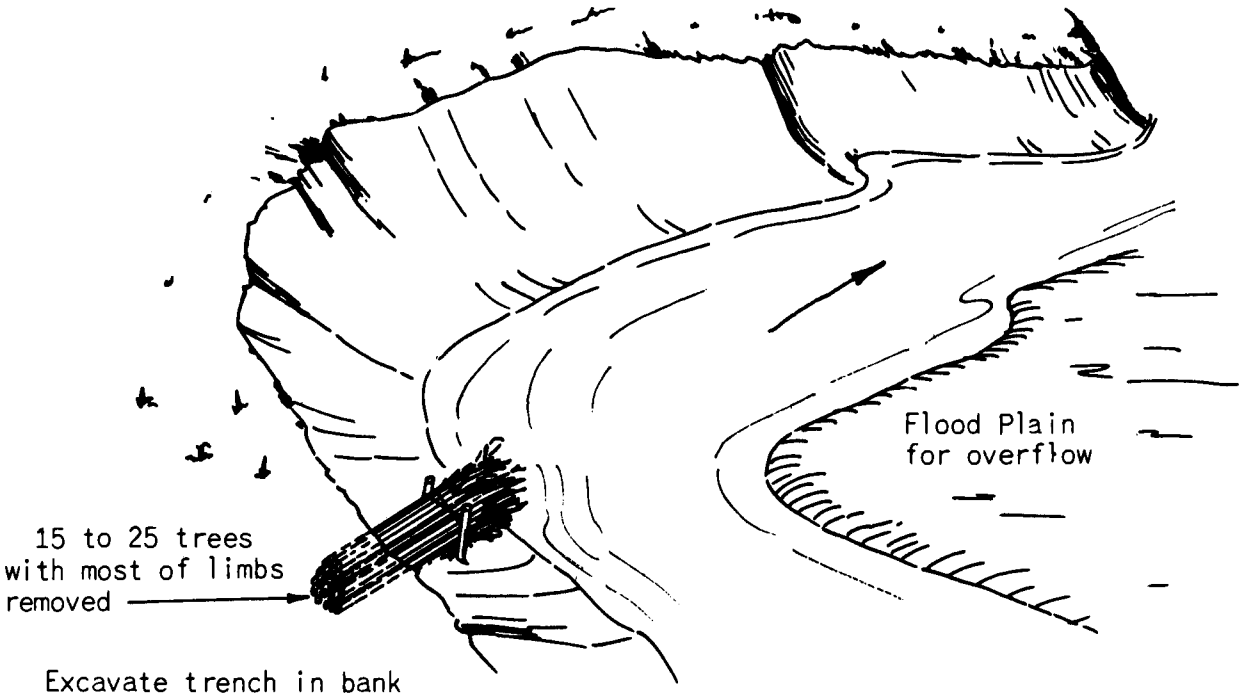

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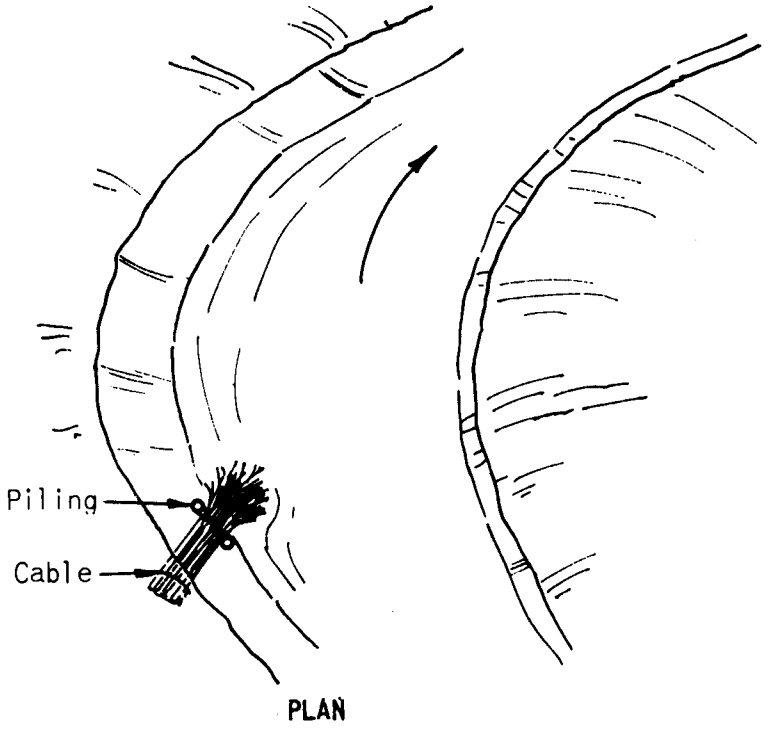

PLAN

Figure 13.9 TREE JETTY

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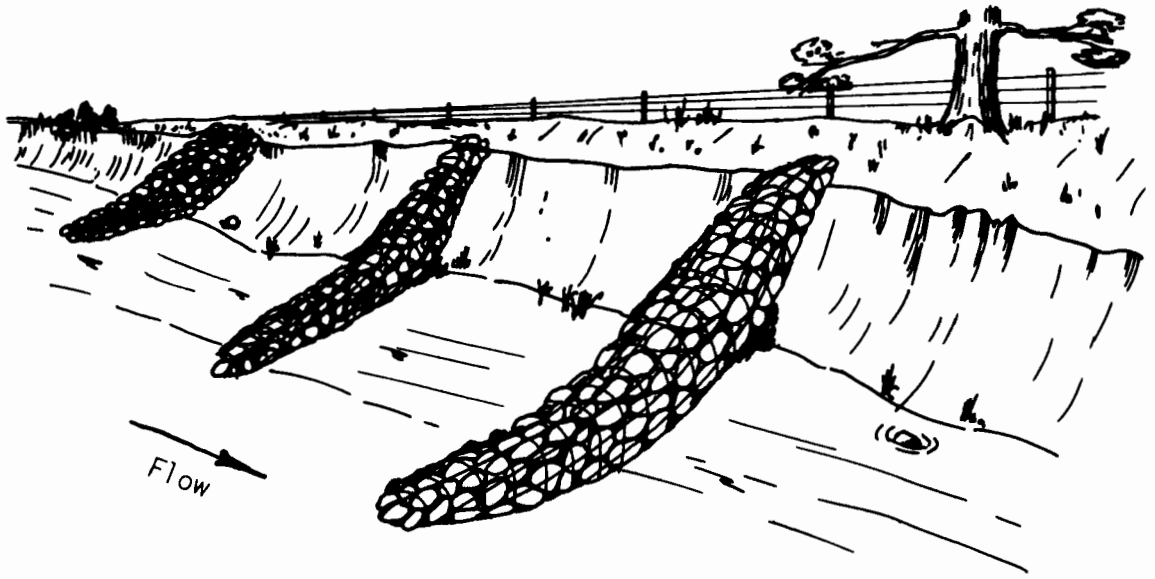
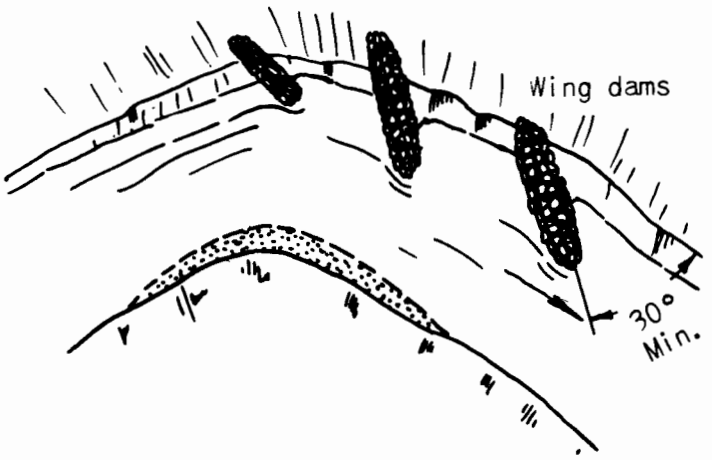
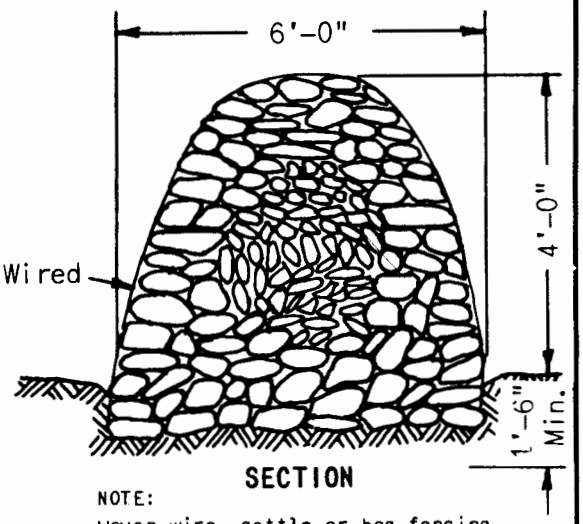




PLAN SHOWING LOCATION OF WING DAMS
OR CURRENT DEFLECTORS



SECTION

NOTE:
Woven wire, cattle or hog fencing, is laid in trench starting with one edge near surface of ground, then wrapped over pile of stone and securely wired to edge of fencing noted above. Wire fence-sections together.

Figure 13.10 ROCK WIRE-BOUND SAUSAGE-TYPE JETTY

4. TREATMENT (CONT'D)

Rock riprap (cont'd)

riprap must be firmly established. If the stream is shallow and has a hard bottom, this is not a serious problem. If the stream bottom is soft and unstable, failure often results. The tendency is to neglect the preparation of an adequate foundation for the bottom course of stone. As the weight increases with the placing of higher courses, the pressure on the bottom course increases and the foundation fails, especially when the toe of the bank is scoured by the stream. As a result, most of the riprap slides into the stream. Soundings should, therefore, be made and cross sections of the stream bed should be plotted before starting to place riprap. Make sure the toe of the slope is stable and that an adequate foundation is provided.

Large stones are best for riprapping. Although small stones are easy to handle they are easily gouged out by ice and carried away by swift currents.

Steep banks should be sufficiently sloped so that the pressure of the stone is mainly against the bank rather than against the stone in lower courses. The slope on which riprap is laid should never be steeper than $1\frac{1}{2}$:1.

The fine material of which streambanks are usually composed must be protected by some blanket of graded material from the attack of waves and the stream current. The large stones of a revetment may withstand the direct attack of the current, but if even gentle flows between these rocks can reach and remove the finer bank material, the large stone may be undermined and failure will result.

The protection blanket for the bank may be provided in two ways.

1. A blanket of well-graded sand and gravel is laid on the bank material and then the larger stone is laid upon it.
2. A graded rock containing sufficient spalls and other fines to fill the voids between the large rocks is placed directly on the bank material.

The latter method has been used extensively and is simpler and cheaper than the first method.

The riprap should extend far enough up the bank to a point where vegetation can be established and provide control. In some cases it will be necessary to carry the riprap to the top of the bank. A combination rock riprap and brush mat revetment is often used. Figure 13.12 shows a cross section of a typical riprapped bank using a brush mat at the top.

5. MAINTENANCE

Continued maintenance of completed stream bank control measures is essential to avoid future, and possible greater, damage later. In planning for maintenance it is important to keep the following points in mind;

1. Control measures, once installed, are not automatically permanent,

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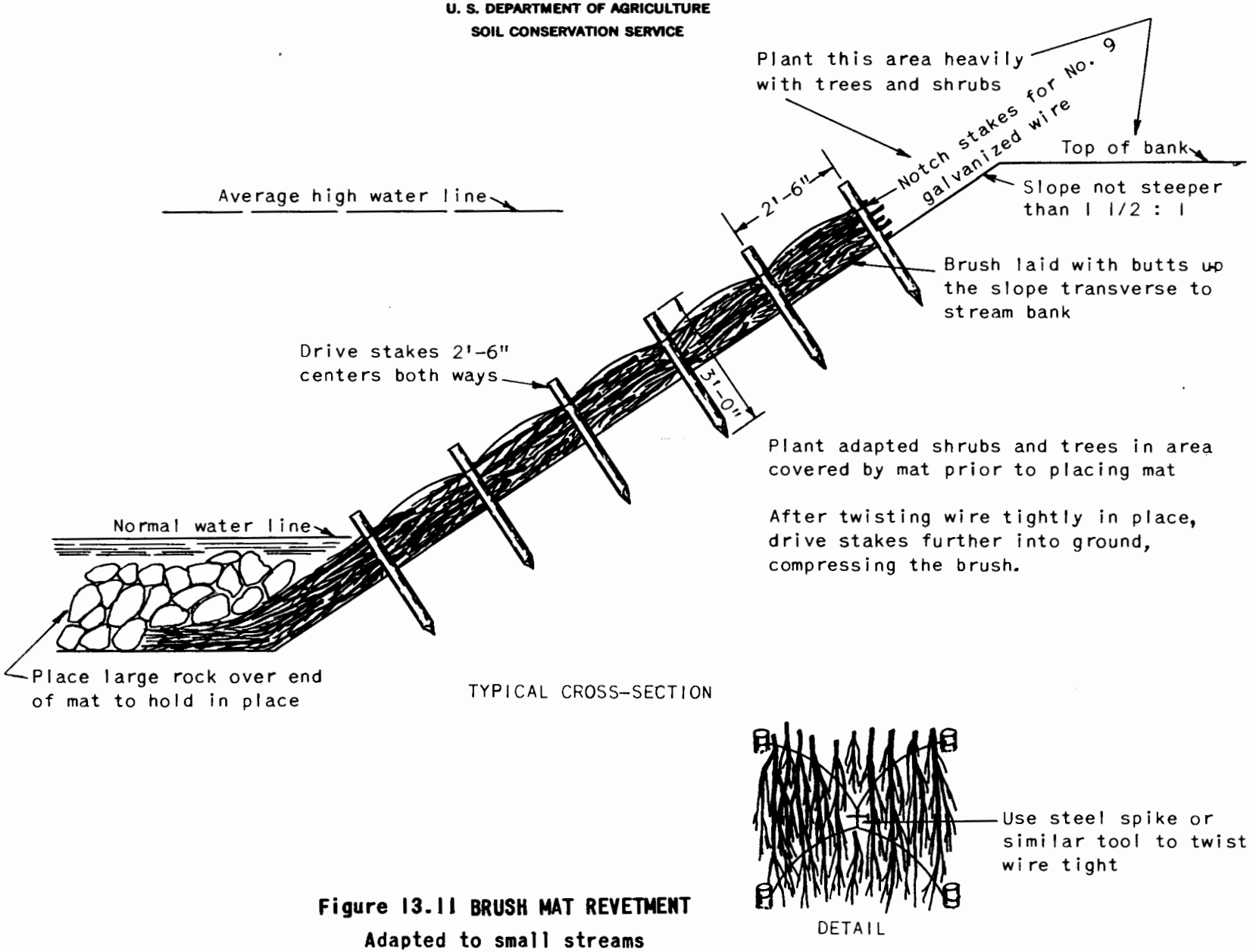
Plant this area heavily with trees and shrubs
Notch stakes for No. 9 galvanized wire
Top of bank
Slope not steeper than 1 1/2 : 1
Average high water line
2'-6"
Brush laid with butts up the slope transverse to stream bank
Drive stakes 2'-6" centers both ways
3'-0"
Plant adapted shrubs and trees in area covered by mat prior to placing mat
After twisting wire tightly in place, drive stakes further into ground, compressing the brush.
Normal water line
Place large rock over end of mat to hold in place
TYPICAL CROSS-SECTION
Use steel spike or similar tool to twist wire tight
DETAIL

Figure 13.11 BRUSH MAT REVETMENT

Adapted to small streams having a firm stream bed

5. MAINTENANCE (CONT'D)

and it usually economically impractical to attempt to establish absolutely permanent controls.

2. The nature of the maintenance differs in different parts of the general drainage area owing to extremes in physical characteristics of rivers and creeks.

Because the vagaries of currents at flood or high-water stages cannot be determined precisely in advance, the amount and intensity of treatment needed cannot be completely foreseen at the start. Careful examination of plantings and structures during the first few years following installation will disclose points of weakness, and sections likely to give way can be strengthened.

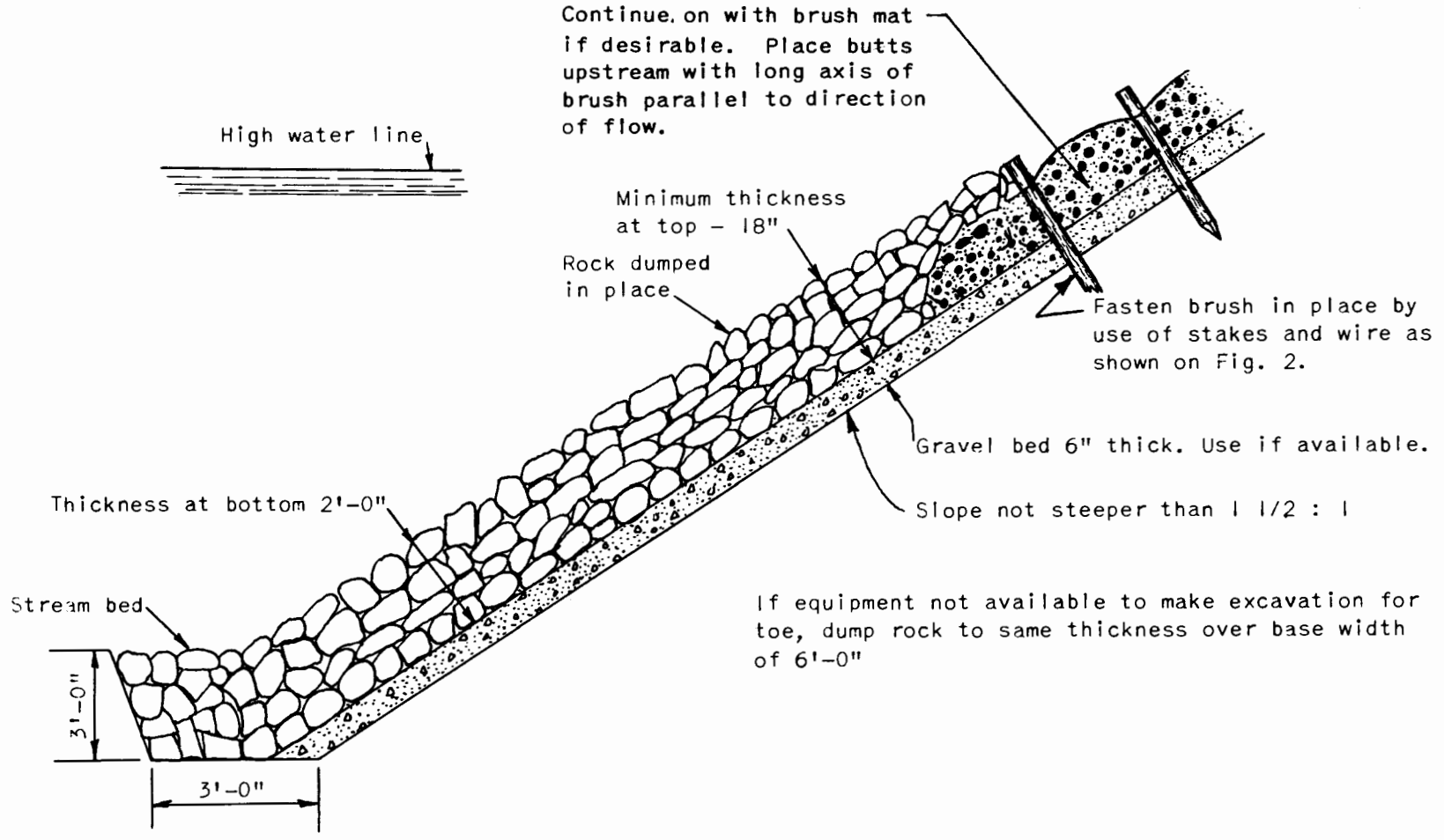
Continue on with brush mat if desirable. Place butts upstream with long axis of brush parallel to direction of flow.
High water line
Minimum thickness at top - 18"
Rock dumped in place
Fasten brush in place by use of stakes and wire as shown on Fig. 2.
Gravel bed 6" thick. Use if available.
Thickness at bottom 2'-0"
Slope not steeper than 1 1/2 : 1
Stream bed
If equipment not available to make excavation for toe, dump rock to same thickness over base width of 6'-0"
3'-0"
3'-0"

Figure 13.12 DUMPED ROCK RIPRAP

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CONTENTS

PART 14

WATER SPREADING

Subject	Page
1. General	14-1
Definition	14-1
State Laws	14-1
Class of Water Spreading Systems	14-1
Types of Water Spreading Systems	14-2
Site Adaptation	14-2
Crops	14-2
Soils	14-3
Topography	14-4
Water Supply	14-4
Location	14-5
Relationship to Other Practices	14-5
2. Surveys and Investigations	14-6
Preliminary Information	14-6
Soils	14-6
Topography	14-6
Drainage Area Size and Characteristics	14-6
3. Design	14-7
Flood Flow Hydrograph	14-7
Special Cases	14-8
Design Application Depth	14-9
Water Supply System	14-10
Diversion Works	14-10
Canals	14-11
Combination Systems, Storage Reservoirs and Pumps	14-12
Capacity	14-15
Water Disposal System	14-16
Flow Type System	14-17
Spreader Ditch Type	14-17
Syrup Pan Type	14-17
Dikes and Bleeder Type	14-20
Detention Type Systems	14-23
Manual Inlet Control Systems	14-23
Automatic Inlet Control Systems	14-26
Example	14-26
Development of the Water Spreading Plan	14-30

Subject	Page
4. Layout	14-30
5. Construction	14-30
6. Maintenance	14-31

LIST OF FIGURES

PART 14

WATER SPREADING

Figure No.	Title	Page
14.1	Class of Water Spreading Systems	14-2
14.2	Design Application for Flow Type Water Spreading Systems	14-10
14.3	Typical Control Structure - Wood Construction	14-13
14.4	Typical Control Structure - Culvert Type	14-14
14.5	Water Spreading Flow and Volume Ratios	14-15
14.6	Flow System - Spreader Ditch Type	14-18
14.7	Flow System - Syrup Pan Type	14-19
14.8	Typical Dike Weirs	14-21
14.9	Dike and Bleeder Water Spreading Systems	14-22
14.10	Detention System - Manual Control Type	14-24
14.11	Check, Turnout and Drainage Structures	14-25
14.12	Automatic Control Type	14-27

PART 14

WATER SPREADING

1. GENERAL

Definition

Water spreading as used in this handbook is a specialized form of surface irrigation accomplished by diverting flood runoff from natural channels or watercourses and spreading the flow over relatively level areas. The diversion and spreading is controlled by a system of dams, structures, dikes, or ditches, or combination of these, designed to accommodate a calculated rate and volume of flow.

It differs from conventional irrigation in that the timing and volume of the water application is not made according to the needs of the crop but is dependent upon the characteristics of the flood hydrograph and the intake characteristics of the soil. Usually the systems require little or no manual control.

State Laws

Applicable state laws or water rights must be considered and observed on the design, layout and construction of water spreading systems and diversion structures.

Class of Water Spreading Systems

The relationship between the expected runoff from the drainage area, the volume of water to be utilized and the moisture needs of the watered areas must be properly balanced. Most water spreading systems should be designed so that the area to be flooded will match the volume of runoff expected on a 1.25 or 2-year frequency (80 or 50 percent chance of occurrence). Figure 14.1 gives the classification of water spreading systems based upon dependability of water supply.

Normally a dependable class system will bring the highest economic return but not all dependable class systems are economically feasible. On the other hand, questionable or even undependable systems may produce enough return to warrant their development. Each case must be judged on its individual merits.

1. GENERAL (CONT'D)

Class of Water Spreading Systems (cont'd)

CLASS OF WATER SPREADING SYSTEMS

Class of System	Description	Design Storm (6 hr. duration) Frequency
Dependable	Frequent flooding can be expected to provide increased production nearly every year.	1.25-year frequency 80 percent chance of occurrence.
Questionable	Beneficial flooding. Increased production can be expected about half of the time.	2-year frequency 50 percent chance of occurrence.
Undependable	Uncertain flooding. Increased production can be expected occasionally.	5-year frequency 20 percent chance of occurrence.

Figure 14.1

Types of Water Spreading Systems

Water spreading systems may be classified into the following types:

1. Flow Type Systems
   a. Spreader ditch systems
   b. Syrup pan systems
   c. Dikes and bleeder systems
2. Detention Type Systems
   a. Manual inlet control systems
   b. Automatic inlet control systems

Further details on each type may be found under "Design", page
Many water spreading systems are a combination of several types.

Site Adaptation

Crops. Water spreading is most frequently applied to range or pasture lands to increase the production of forage, hay or seed and usually is associated with a non-intensified type of agriculture as distinguished from intensified crop production under irrigation.

1. GENERAL (CONT'D)

Site Adaptation (cont'd)

Crops (cont'd)

In arid or semi-arid areas, additional moisture on range or pasture land improves the quality of the forage and lengthens the periods of growth. Water spreading often allows the development of hay fields in areas where hay cannot otherwise be grown. It may permit seed production of alfalfa or native grasses.

Water spreading on native grass stands will increase the percentage of mid and tall grasses. Adapted native grasses for seeding on medium to heavy soils are western, slender wheatgrass and green needlegrass. Legumes are limited to alfalfa and sweetclover. Refer to the local technical standards for the adapted grasses and/or legumes along with the necessary fertilizers for a particular area. Since the areas of water spreading will be determined as dependable, questionable and undependable and maximum production is the ultimate goal, consideration can be given to using tame grasses supported by adequate fertilizers on the dependable areas and native grasses on the other areas.

Water spreading should not be done on annual crops unless ponding methods are utilized. Special precautions must be taken to prevent erosion and usually problems arise in planting, cultivating and harvesting. For these reasons it generally is not recommended.

Detention type systems may be required on heavy soils to hold the water on the surface of the soil for a considerable period to provide opportunity for infiltration. Under these conditions, the crop must be of a type that will tolerate these periods of prolonged inundation.

Soils. Deep medium to moderately fine textured soils over moderately permeable subsoils and moderately permeable substrata are ideally suited to water spreading. Coarse and moderately coarse textured soils should be avoided because the soil will absorb the water so rapidly that it is difficult to convey over the area. Coarse soils have low water holding capacity and do not make effective use of flood waters applied at infrequent intervals.

Heavy and moderately heavy soils are satisfactory if the slope of the land is such that a detention type system can be employed. This is necessary because usually the intake characteristics of these soils are such that the root zone cannot be filled in the length of time that runoff occurs.

1. GENERAL (CONT'D)

Site Adaptation (cont'd)

Soils (cont'd)

Soils which contain an excessive amount of soluble salt are not suitable for water spreading. Leaching of soluble salt concentrations from the soil usually cannot be accomplished for the amount of water applied during each application is seldom sufficient to fill the root zone to field capacity. Sufficient gravitational water is not normally available to carry the salts beyond the root zone.

Indicator plants can be used as a guide to recognize sites which may be high in alkalinity or salinity. Sagebrush indicates low salinity and alkalinity. Winterfat, rabbit brush, greasewood, saltwort, saltgrass or alkali sacaton are indicative of wet, saline or light textured soils.

Topography. It is difficult to apply water uniformly over a water spreading area unless the topography is broad, smooth and gently sloping. The site should be free from rills or channels. It is usually not considered economically feasible to level land on which floodwater is to be spread.

Detention type systems are limited to slopes of 1 to 2 percent or less, because if placed on steep slopes, the spacing between the dikes becomes quite narrow or high dikes are required. Low dikes are preferred because they permit better utilization of the water and are not subject to severe wave action. Low heads of water also are desirable to avoid dike failure. The volume of earthwork per acre required to construct the dikes increases rapidly as the slope increases.

Flow type systems using spreader ditches or dikes are limited to slopes of three (3) percent or less generally, although where slopes are very smooth and a sod type vegetation is present, they may be applied on slopes up to five (5) percent.

The minimum slope required is that which will provide for drainage of the excess water. A somewhat higher minimum slope is required when the water carries a high sediment load. It is then necessary to have sufficient slope to prevent the deposition of the sediment as a cone or bar near the inlet to the area.

Water Supply. The seasonal distribution of the runoff producing storms or the period of runoff from snow melt is an important characteristic of the water supply for a water spreading system. Early spring runoff may find the soil frozen and not in a condition to absorb water and late fall runoff may not be of much help if normally the soil is

1. GENERAL (CONT'D)

Site Adaptation (cont'd)

Water Supply (cont'd)

saturated over the winter months. Water spread at a time when the soil profile is at nearly field capacity will be largely ineffective.

The precipitation pattern in the Northern Great Plains lends itself to the successful operation of water spreading systems. Here the total precipitation during the summer months may be inadequate to meet the needs of the crop but storms of high intensity occasionally occur during the spring and summer months.

Normally, flood waters are of satisfactory quality for water spreading from a standpoint of salt or sodium content. However, they may carry appreciable quantities of sediment. They may be either beneficial or detrimental, depending upon volume and type. Fine grained sediments, which may be expected to be deposited uniformly over the spreading area, may be beneficial rather than harmful. They actually may improve soil fertility or may tend to settle out in low ponded areas improving the topography.

Flows which carry heavy bed loads are difficult to utilize. Most of the diverted load will be dropped in the diversion works or spreading area and will cause problems of maintenance. Waters which carry selenium or arsenic sediments or other deleterious minerals should not be used.

Proper land use on the drainage area is essential. Conservation practices applied on the drainage area will improve the vegetal cover and reduce erosion and sediment production. However, conservation work on the drainage area may be expected to reduce peak flow and water yield.

Location. Water spreading systems which are unaccessible during rainstorms or which lie at a distance from the ranch headquarters should be automatic or semi-automatic in nature. This tends to make the system more expensive and to increase maintenance costs.

Relationship to Other Practices

Sites are not always suitable for water spreading, even though there is a need for restoration and improvement of the grassland. Other methods, such as proper range management, contour furrowing or pitting, may be more effective in reducing runoff and improving soil moisture conditions. Contour furrowing or pitting can be applied on the water spreading area to increase penetration of water into heavy soils.

2. SURVEYS AND INVESTIGATIONS

Preliminary Information

The survey information necessary on a water spreading system depends upon the size of the system, the topography of the diversion and spreading area, and the type of system to be installed. Simple spreading systems require a minimum of information. They consist of diversions from small watercourses and contour spreader ditches on sloping land to redistribute the water wherever it begins to concentrate. Complex systems diverting large volumes of water into ditch and dike areas on gently sloping lands require detailed surveys.

Soils. Soil types that are suited for water spreading are the same as for irrigation. Prior to final selection of a site for water spreading it is necessary to have a soils survey map showing the following: (1) effective depth; (2) texture of the surface soil; (3) permeability of the surface, subsoil, and substratum; and (4) the erodibility of the soil.

The soil of the proposed water spreading area should be studied to determine whether or not it has the fertility needed. Nitrogen may be needed to increase the forage growth, and phosphate required where seed production is desired. Fertilizer recommendations should be based upon soil tests or field trials.

Topography. Sketch maps should be prepared for simple water spreading systems using contour spreader ditches. Topographic maps are necessary on more complex systems to enable proper design. These maps should cover the diversion site, diversion ditch area, the proposed water spreading and disposal area. Refer to Part 1 for procedures and methods to use in preparing the topographic map. On all water spreading projects serving five (5) or more acres, a topographic map should be made. The contour interval in feet should approximate the land slope in percent. The horizontal map scale should be 200 to 400 feet per inch.

Drainage Area Size and Characteristics. The drainage area should be delineated to determine the size, shape, and characteristics. For smaller drainage areas, the boundaries can be traced from aerial photos and all major drainageways and channels shown. Other features, such as existing storage dams, road culverts and bridges, and others, should be noted on the tracing. Soil types or range sites, slopes, type and extent of vegetal cover, or other land use and condition should be shown. Slopes and lengths of the main channels should be determined. Long drainage areas can be expected to have different peak flow and duration characteristics than those that are fan shaped. Long narrow drainage areas will have a longer time of concentration as well as duration of flow. Storms which are not great in aerial extent may move across a narrow drainage area producing runoff from just part of the total area, while it may cover most of a fan-shaped drainage area.

2. SURVEYS AND INVESTIGATIONS (CONT'D)

Preliminary Information (cont'd)

Drainage Area Size and Characteristics (cont'd)

The drainage area should be inspected to estimate the volume and nature of sediment production to be expected, and consideration given to corrective measures that will reduce this volume. Eroded soils, bare slopes, and active gullies will increase the volume of sediment produced during storm periods. Often the grade and deposition in the main channels will be indicative of the volume. The sediment may be carried as a suspended load in the water or be deposited as a bed load when the velocity of the water is reduced.

3. DESIGN

The depth of water which can be applied to a water spreading area is dependent upon the characteristics of the flood hydrograph, the characteristics of the soil, and the type of system used.

Although four basic types of water spreading systems will be explained and described, it may be necessary to design and construct systems that combine two, or even more, of the suggested types. Combination systems may be feasible or desirable to more fully recognize differences in topography or soils.

The basic elements requiring design are the diversion works and canal systems, the spreader ditches, dikes, structure, etc., on the spreading area and the water disposal system.

Flood Flow Hydrograph

The characteristics of the flood flow hydrograph are determined in accordance with Part 3 of the handbook. Separate calculations should be made for each of the following storm frequencies:

1.25 year	80% Chance	Dependable Class System
2 year	50% Chance	Questionable Class System
5 year	20% Chance	Undependable Class System

The following steps are followed for storm runoff:

1. From Figure 3.1, determine the expected storm rainfall (P) in inches.

   Note: The storm rainfall for a 1.25 year frequency can be determined by multiplying the 2 year frequency storm rainfall by 0.8.

3. DESIGN (CONT'D)

Flood Flow Hydrograph (cont'd)

2. Knowing the soil cover complex number for the drainage area, from Figure 3.5 determine the expected direct runoff (R).

3. Compute the volume of storm runoff:

$V_s = 640\ RA$

Where V_s = Volume of storm runoff in acre-inches

R = Direct runoff in inches

A = Drainage area in square miles

4. Compute the time of concentration (T_c) in accordance with the procedure given in Part 3 of the handbook.

5. Determine the unit peak discharge (q) from Figures 3.6 and 3.7.

6. Compute the peak discharge.

$Q = q\ A\ R$

Where Q = Peak discharge in cfs

q = Unit peak discharge in $cfs/mi^2/in$

A = Drainage area in square miles

R = Direct runoff in inches

Special Cases. When the flood flows are produced by melting snows, special procedures are required which are beyond the scope of this handbook.

In some instances the supply canal is located at a considerable height above the bottom of the stream channel and a dam provided to raise the water into the canal. In these instances an appreciable volume of the runoff is required to fill the reservoir behind the diversion structure and this volume must be deducted from the computed flood flow volume. Likewise, the storage capacity of any large reservoirs in the drainage area should be deducted.

3. DESIGN (CONT'D)

Flood Flow Hydrograph (cont'd)

Special Cases (cont'd)

In other instances, detention reservoirs may be constructed above the point of diversion. These tend to reduce the peak flow (Q) and to prolong the duration of flow. The modified hydrograph must then be determined by flood routing procedures.

Occasionally, when a stream channel carries considerable bed load, the diversion inlet may be placed a small distance above the bottom of the stream so that the bed load will not be diverted into the canal. This procedure by-passes low flows and reduces the volume of water available for the spreading area.

All of these special cases require individual evaluation and should be referred to the Area Engineer.

Design Application Depth

On flow type systems, the depth of application is affected only by the duration of flow and the intake characteristics of the soil.

Figure 14.2 gives design depth of application (d_a) and estimated flow durations for free flow systems with various times of concentration (T_c) for various soil textures ranging from medium to very fine. As an illustration, it has been determined that for a T_c of 2 hours the estimated flow will approximate 10 hours. On medium textured soils (M) approximately 9.6 inches would be absorbed by each acre that was flooded for 10 hours. For moderately fine soils (F) about 5.4 inches of water would enter the soil in 10 hours of flow time.

With detention type systems the depth of application can be made equal to the water holding capacity of the top three feet of the soil profile. The estimated water-holding capacity for the soils can be obtained from the irrigation guide. In a detention type system, the depth of application is not dependent upon the duration of flow, provided the volume diverted is large enough to supply the design application depth.

3. DESIGN (CONT'D)

Design Application Depth

DESIGN APPLICATION FOR FLOW TYPE WATER SPREADING SYSTEMS

DRAINAGE CHARACTERISTICS		SOIL TEXTURE			
Time of Concentration (T_c)	Estimated Flow Duration	M Medium	F Mod. Fine	H Fine	V Very Fine
Hours	Hours	Inches	Inches	Inches	Inches
0.5	8.5	*1 8.5	*2 4.8	*3 2.9	1.6
1.0	9.0	8.9	5.0	3.0	1.6
1.5	9.5	9.3	5.2	3.1	1.6
2.0	10.0	9.6	5.4	3.2	1.7
2.5	10.5	9.9	5.5	3.2	1.7
3.0	11.0	10.2	5.7	3.3	1.8
3.5	11.5	10.5	5.9	3.4	1.8
4.0	12.0	10.9	6.0	3.5	1.9
4.5	12.5	11.2	6.2	3.6	1.9
5.0	13.0	11.5	6.3	3.7	1.9
5.5	13.5	11.8	6.5	3.7	1.9
6.0	14.0	12.3	6.7	3.8	2.0

*1 A free flow system is adequate for these soils.
*2 These soils are adapted to either flow or detention type systems.
*3 Detention type systems should be given first choice.

Figure 14.2

Water Supply System

Diversion Works. Diversion works may be of various types. The type to use is dependent upon the size and nature of the flows to be expected, and the relative location and elevation of the spreading area.

Base grade diversions should be given first consideration if they are adaptable. Here, the canal section intercepts the bottom of the stream channel. The inlet to the canal should be higher than bottom grade of the dry draw if the runoff water carries a high sediment bed load, and lower if the water is clear.

3. DESIGN (CONT'D)

Water Supply System (cont'd)

Diversion Works (cont'd)

A control structure generally is needed in the excavated canal to permit only the design flow of water into the system and force the remainder of the flow to continue down the stream. Also, it may be necessary to prevent flow into the spreading area during the haying or harvest season or at times when maintenance work is being performed. Control structures may be of various types - an earth fill with a gated metal or concrete pipe through the earth fill, or a concrete, metal or wood headgate equipped with slide gates or flashboards.

. A dam may be constructed across the channel to raise the water to the elevation of the supply canal whenever the topography will not permit a base grade diversion. All the general principles of dam construction must be observed, including necessary provisions for by-passing the floodwater. Earth dams can be built where a good natural or excavated spillway can be provided. The principles involved in earth dam construction are outlined in Part 9 of this handbook. When using earth dam diversions, it may be possible to place the inlet of the supply canal at an elevation below the crest of the spillway and utilize temporary storage following a runoff period extending the duration of flow. Overflow structures can be built of concrete or rubble masonry, rock and brush, timber cribs filled with rock, or steel sheet piling cribs filled with rock. Ordinarily, such dams should not be over four (4) or five (5) feet in height. Normally these structures require an engineering design.

Canals. The route of the canal from the diversion works to the spreading area should provide for the shortest practical length. The water section should be kept in cut (below the natural ground surface) as far as practicable, and construction of fills or embankments should be avoided. Where it is difficult to locate a canal so as to place the water section wholly in excavation, compacted embankments should be constructed. Sharp curvature of the canal should be avoided. Provisions must be made to safely convey or dispose of drainage waters which may enter the canal along its route.

Grade and Velocity - Part 16 of the handbook provides information on grades for ditches and permissible velocities. Also, the friction factor "n" to be used in Manning's formula is given.

3. DESIGN (CONT'D)

Water Supply System (cont'd)

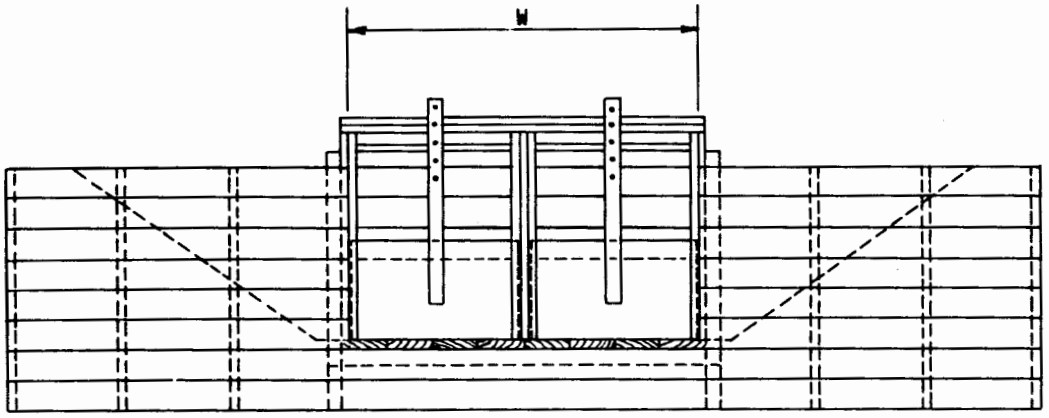
Canals (cont'd)

The canal section should be selected by considering its flow properties, stability, freeboard, and the machinery that will be used for construction. A canal section which approximates a half circle will have the highest mean velocity and thus the greatest flow capacity for the size. On the other hand, canals in which the bottom width is large in comparison to the flow depth will have a much lower mean velocity since more energy is dissipated in overcoming friction along the perimeter of the section. The bottom width commonly used ranges from 2 to 8 times the flow depth. The stability of the materials determines the side slopes to be used. Side slopes of $1\frac{1}{2}$:1 are usually considered minimum. On side hill locations, 1:1 slopes can be used to avoid excessive excavation, provided the materials are stable and the canal is protected against side hill runoff. The top width of canal banks should not be less than 3 feet, or 12 feet if they are to be used as roadways.

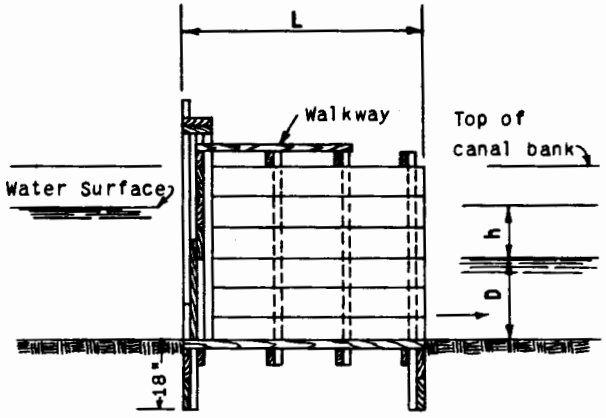
Freeboard - The distance from the design water surface to the top of the vegetated banks should not be less than two-tenths of the flow depth in flat areas, or one-half the flow depth where the banks are bare of vegetation and/or where the topography is steep.

Structures - Figures 14.3 and 14.4 show typical structures that can be used in the main supply canals. The structures can be wood, metal, or concrete.

Combination Systems, Storage Reservoirs and Pumps. Under some conditions and in some states, reservoirs to store water can be used in combination with water spreading systems. Reservoirs are desirable since the duration of flow can be prolonged or the application delayed for a period of time. Many of the variables which affect a system are removed when storage is provided. Where the streams flow for prolonged periods of time pumps may be used to supply water from streams where direct diversion is not feasible.



ELEVATION

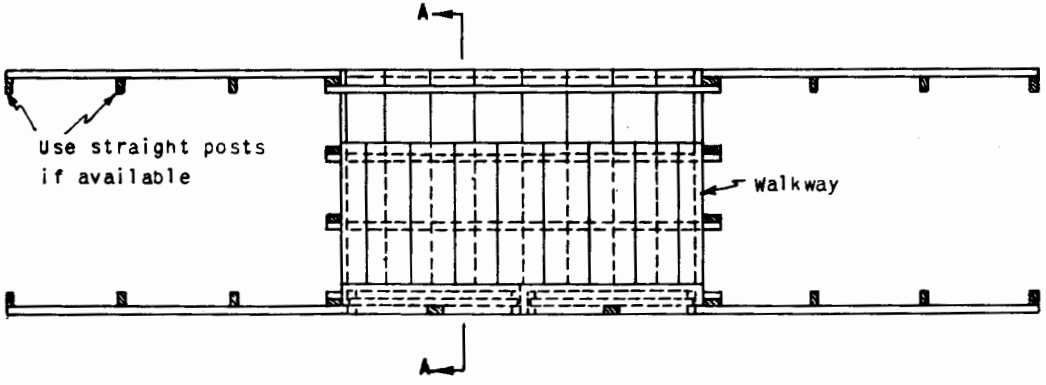


SECTION A - A

$Q = CA\sqrt{2gh}$

$W = \frac{A}{2D}$ where A = Water section area of ditch
D = Depth of water in ditch

L = 2 x Maximum depth of water on upstream side of gate



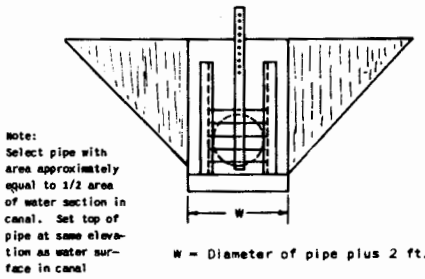
PLAN

NOTE:
Place well tamped backfill around all cut off walls. Grade foundation carefully to provide close contact with timber floor. Make all joints as watertight as possible. Use 2" plank construction throughout.

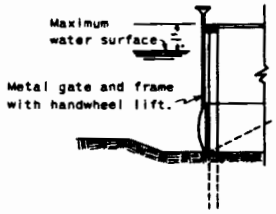
TYPICAL CONTROL STRUCTURE
WOOD CONSTRUCTION

59M-82

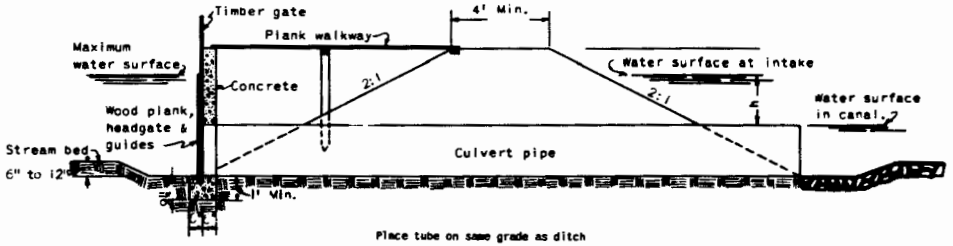
Figure 14.3


Note:
Select pipe with area approximately equal to 1/2 area of water section in canal. Set top of pipe at same elevation as water surface in canal
W
W = Diameter of pipe plus 2 ft.

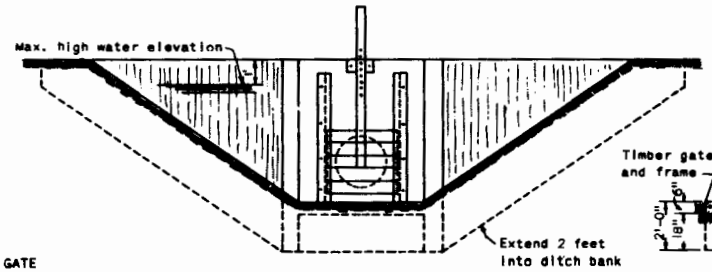
UPSTREAM ELEVATION TIMBER GATE



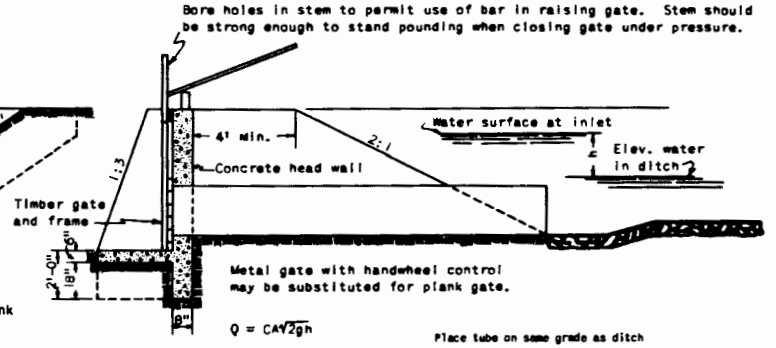
ALTERNATE GATE INSTALLATION



SECTIONAL ELEVATION-CENTER LINE



ELEVATION


Bore holes in stem to permit use of bar in raising gate. Stem should be strong enough to stand pounding when closing gate under pressure.
Water surface at inlet
4' Min.
2:1
Elev. water in ditch
Concrete head wall
1:3
Timber gate and frame
2'-0"
18"
8"
Metal gate with handwheel control may be substituted for plank gate.
Q = CA√2gh
Place tube on same grade as ditch

SECTION

PRESSURE REQUIRED TO OPERATE GATE

F = the force required to operate gate, in pounds.

A = the gross area of gate in square feet.

H = the head, in feet, from water surface to center of A

K = the coefficient of static friction, 0.5 – Wood on wood, 0.7 – Wood on concrete

W = weight of gate in pounds. Corrected for submergence.

To open gate: F = 62.5 HAK + W

To close gate: F = 62.5 HAK – W

TYPICAL CONTROL STRUCTURE CULVERT TYPE

59M-82

Figure 14.4

3. DESIGN (CONT'D)

Water Supply System (cont'd)

Capacity. The water supply system must be designed to have adequate capacity to divert the required volume of water onto the spreading area within the period of time that storm flow occurs. This required volume may be computed:

$$V_d = d_a\, a$$

Where V_d = Required volume to be diverted in acre-inches

d_a = Design application depth in inches

a = Spreading area in acres

The value V_d (diverted volume) can never be greater than the value V_s (storm volume). In most instances it will be found most practical to divert somewhat less than the full storm flow. In these instances the required capacity of the water supply system can be computed with the aid of Figure 14.5.

WATER SPREADING FLOW AND VOLUME RATIOS

Ratio $\frac{Q_d}{Q}$	r_v
0.000	0.000
0.100	0.180
0.200	0.350
0.300	0.505
0.400	0.635
0.500	0.750
0.600	0.840
0.650	0.875
0.700	0.910
0.750	0.935
0.800	0.955
0.850	0.975
0.900	0.985
0.950	0.995
1.000	1.000

Ratio $\frac{V_d}{V_s}$	r_q
0.000	0.000
0.100	0.055
0.200	0.110
0.300	0.165
0.400	0.230
0.500	0.295
0.600	0.370
0.650	0.410
0.700	0.455
0.750	0.500
0.800	0.555
0.850	0.610
0.900	0.685
0.950	0.780
1.000	1.000

Figure 14.5

3. DESIGN (CONT'D)

Water Supply System (cont'd)

Capacity (cont'd)

Thus, if the spreading area (a) is first determined, the required diversion volume (V_d) can be computed and the ratio V_d/V_s calculated. The required diversion flow is then

$$Q_d = r_q Q$$

Where Q_d = Required diversion flow in cfs

r_q = Value from Figure 14.5 for calculated ratio V_d/V_s

Q = Peak flow from drainage area in cfs

Contrariwise, if the diversion flow (Q_d) has been established by site limitations, the volume of water available for spreading can be computed.

$$V_d = r_v V_s$$

Where V_d = Diverted volume in acre-inches

r_v = Value from Figure 14.5 for calculated ratio Q_d/Q

V_s = Storm runoff volume in acre-inches

Water Disposal System

It is necessary to make provisions for removing excess water from the system and returning it to the channel from which it was originally diverted. It may be diverted into channels other than the original if this can be done without causing erosion, possible damage to other interests or violation of state laws. The excess water may be caused by a heavy rain or by applying water in excess of the intake capacity of the soil. This excess water can be conveyed from the spreading area in natural channels or in constructed channels. The channels should be such that the water will not attain an erosive velocity. Broad, shallow channels with a vegetative cover are desirable. Where the spreading area is considerably higher than the stream, and a broad, gently sloping bank leading to the stream is not available, drops or chutes may be required to lower the water to base grade of the stream channel.

3. DESIGN (CONT'D)

Flow Type Systems

Flow type systems comprise methods that incorporate free drainage from the spreading area. Various methods are employed to spread the water and the surface water disappears from the area soon after the inlet flow ceases.

Spreader Ditch Type. Spreader ditches are very useful in distributing a concentrated flow of water over an area. These ditches are constructed so that the water surface will be very slightly above the field surface and no dike is utilized. The excavated material is usually wasted on the upstream side of the spreader. Since the capacity of the ditch must be reduced as the distance from the water source is increased, the ditch is constructed with a variable grade. Usual practice is to use a grade of 0.3% or 0.4% on the upper end of the ditch and then reduce the grade to zero by equal increments of length.

Figure 14.6 shows typical spreader ditch installations. The upper ditch conveys the water onto the area while the ditches below pick up the water that tends to concentrate in channels and respreads it.

Spreader ditches on smooth slopes should not be more than 300 feet apart. Contour furrows between spreader ditches are helpful in keeping the water from channeling.

These systems are best adapted for use with small drainage areas or in combination with other types of systems. They are limited to slopes of 5 percent or less and always on grassed areas.

Syrup Pan Type. The syrup pan type takes its name from the old method used to boil sap down to syrup. In this, sap was forced to flow back and forth over an inclined pan.

A typical syrup pan type water spreading system is shown in Figure 14.7. Usually this type system should not be installed on slopes over 1.2%.

The supply canal may be constructed on the upper side of the area and the water delivered to the upper contour dike by means of a spreader ditch or several openings in the supply canal. An inlet control structure or a relief spillway should be provided in the supply canal so that the upper contour dike will not be overtopped.

The end openings in the contour dikes should be so proportioned that they will discharge the flow with a depth equal to the vertical interval of the dikes. Contour dikes are constructed from borrow on the lower side so that the cut section may serve to spread the water over the area below. Trail dikes should be provided at intervals not over 300 feet.

FLOW SYSTEM SPREADER DITCH TYPES

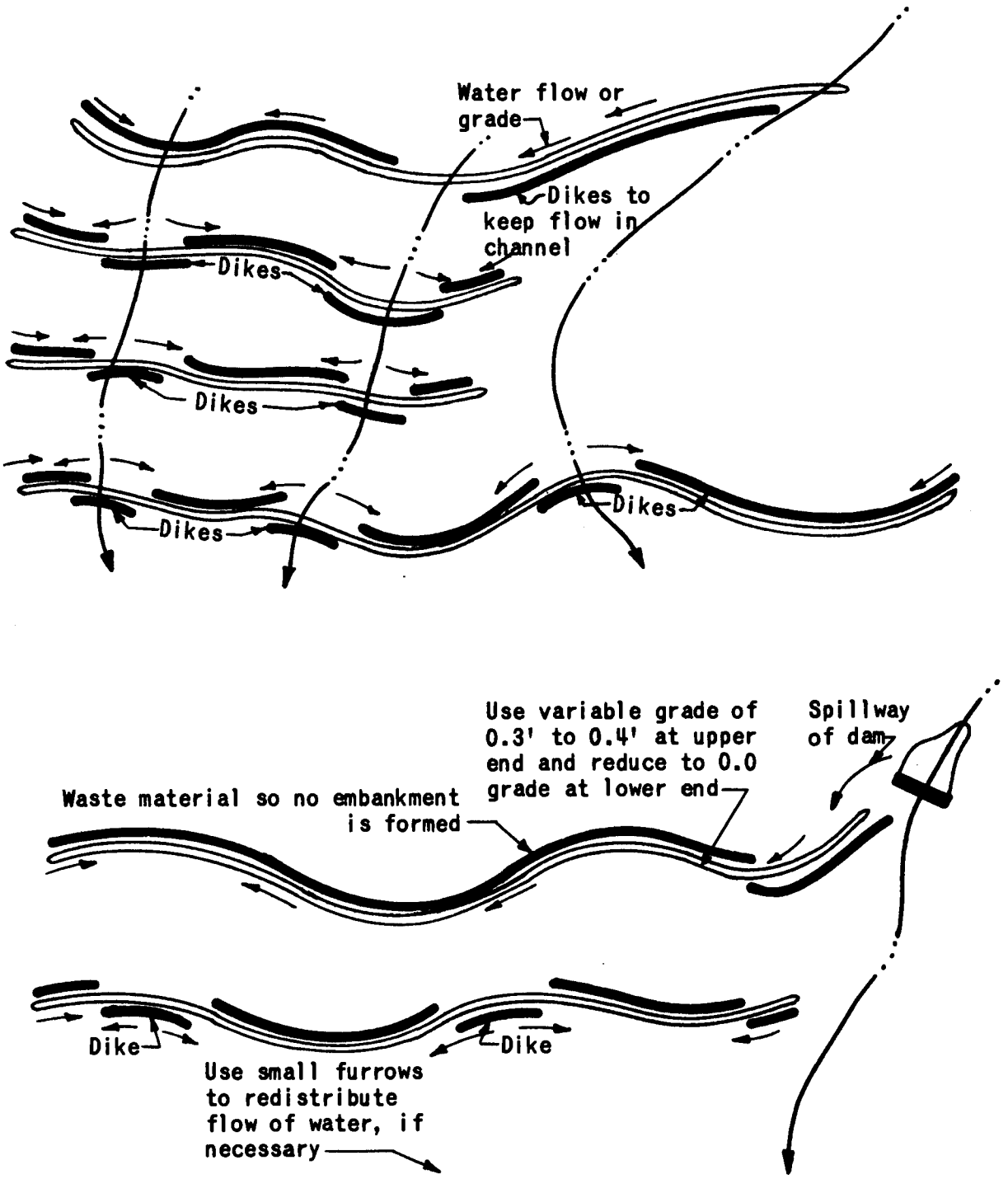
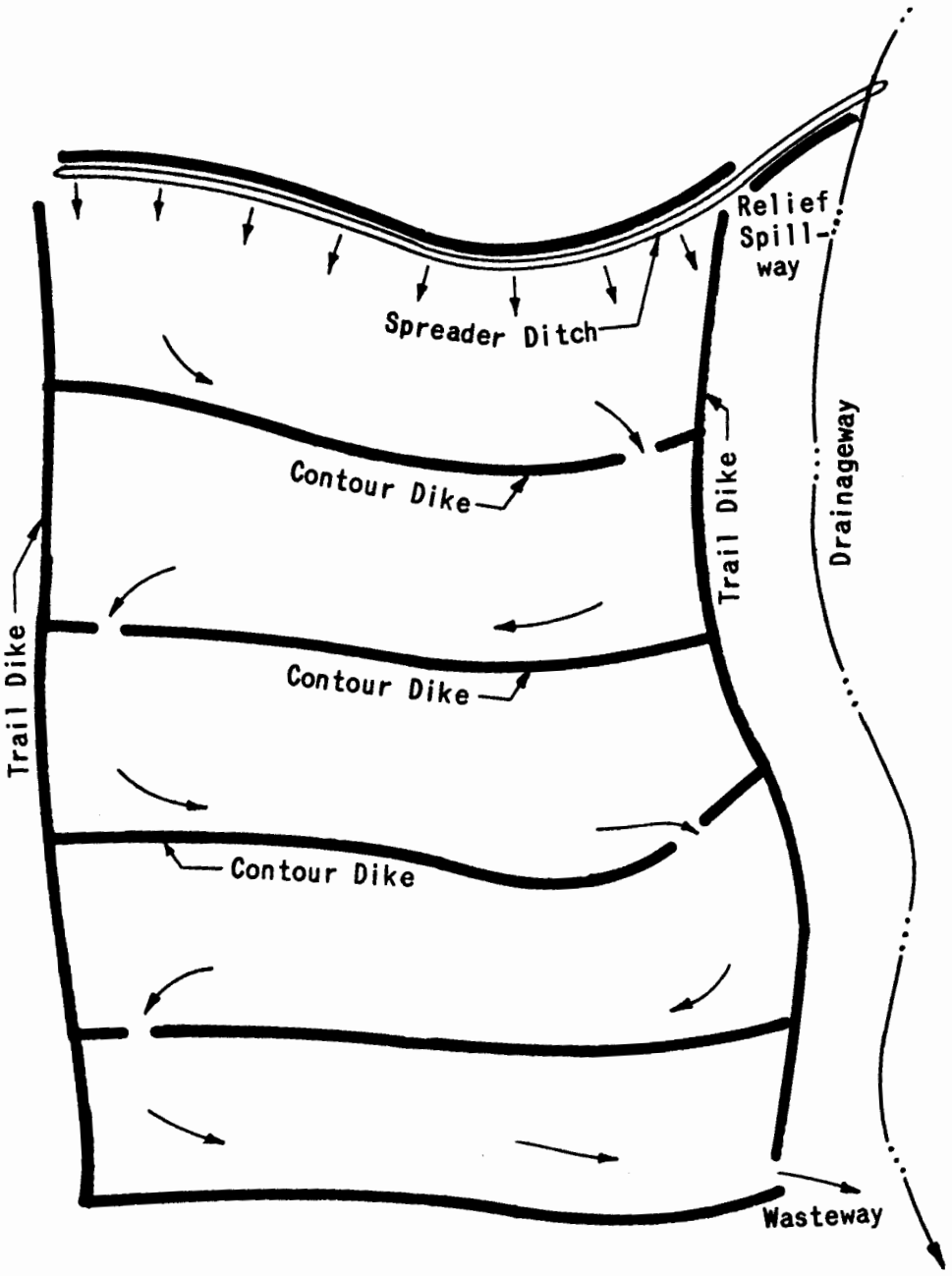
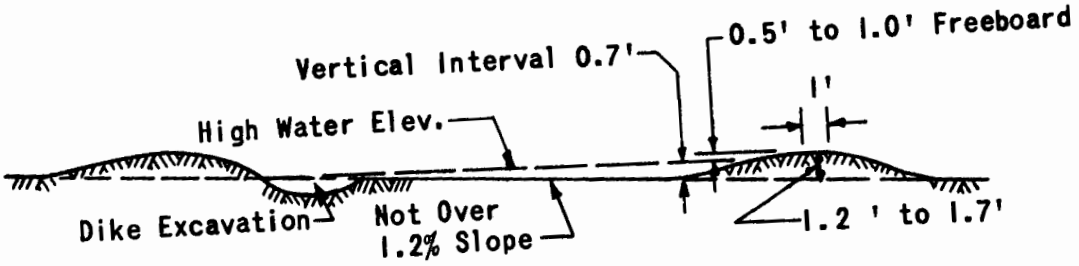

Water flow or grade
Dikes to keep flow in channel
Dikes
Dikes
Dikes
Dikes
Use variable grade of 0.3' to 0.4' at upper end and reduce to 0.0 grade at lower end
Spillway of dam
Waste material so no embankment is formed
Dike
Dike
Use small furrows to redistribute flow of water, if necessary

Figure 14.6

59M-82

SYRUP PAN TYPE WATER SPREADING SYSTEM





SECTION THROUGH DIKES

Figure 14.7

59M-82

3. DESIGN (CONT'D)

Flow Type Systems (cont'd)

Syrup Pan Type (cont'd)

Syrup pan systems are primarily adapted to small flows since large streams require high dikes, entailing high construction and maintenance costs.

For larger stream sizes (over 6 to 10 cfs) the area may be developed as two or more systems side-by-side. There is practically no limit to the width of the area that can be served, providing the openings in the supply canal are properly distributed.

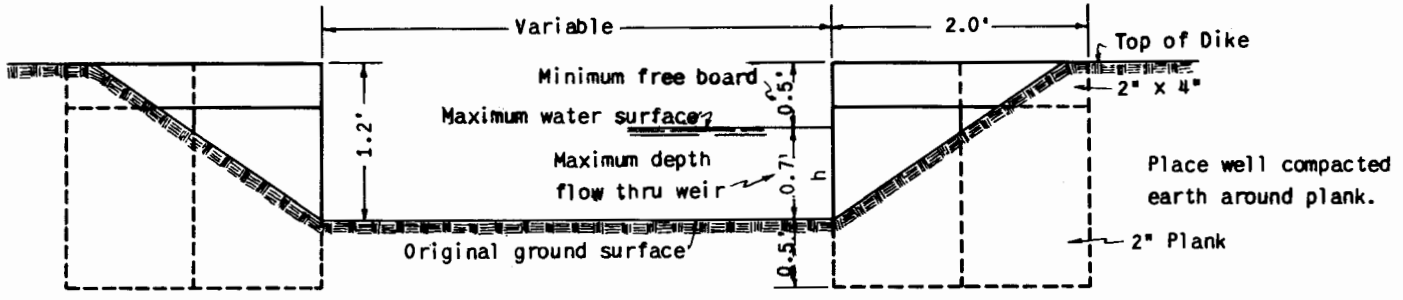
The downslope length of the syrup pan system must be such that the area on which water is to be spread is correctly proportioned to the volume of water which can be discharged into the area during the period of flood flow.

The maximum depth of water which is governed by the dike spacing and height should not exceed 0.7 foot under average conditions. The freeboard should not be less than 0.5 foot, so the total dike height generally should be about 1.2 feet. The openings through the dikes can be culvert pipes, orifices, or weirs similar to Figure 14.8. Riprapped openings or sod openings in the dike may be used where soil materials are stable.

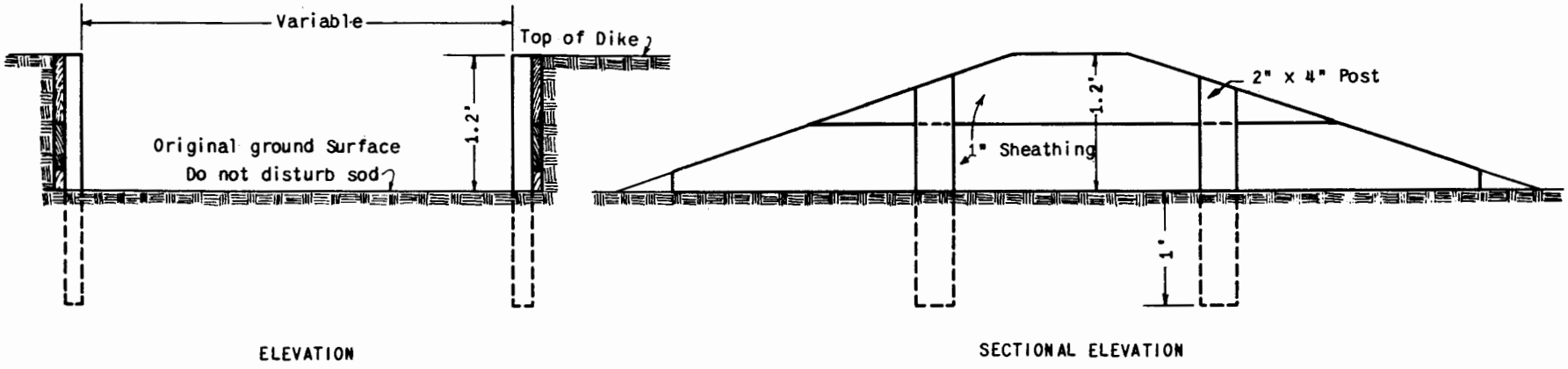
Dikes and Bleeder Type. A modification of the syrup pan system is to install many small bleeders through the dike instead of a single outlet. Orifice tubes made from concrete, clay, or metal pipe may be utilized to by-pass water from one diked area to the ones below. These structures should have a total design capacity equal to the application stream size when operating under a head equal to the vertical interval between the dikes. When orifice type bleeders are used, it is well to have a provision for an emergency wasteway to prevent damage to the dikes should some of the orifices become clogged with trash.

Figure 14.9 shows an example of a water spreading system using dikes with bleeders.

A still further modification of the dike and bleeder system is to use several openings in the dikes instead of orifice tubes. In this instance, the total weir flow capacity of the openings at the design depth of flow should equal the total stream size. Sod, riprap, or structures similar to Figure 14.8 may be used to protect the dikes from washing at the openings.



TYPE 1

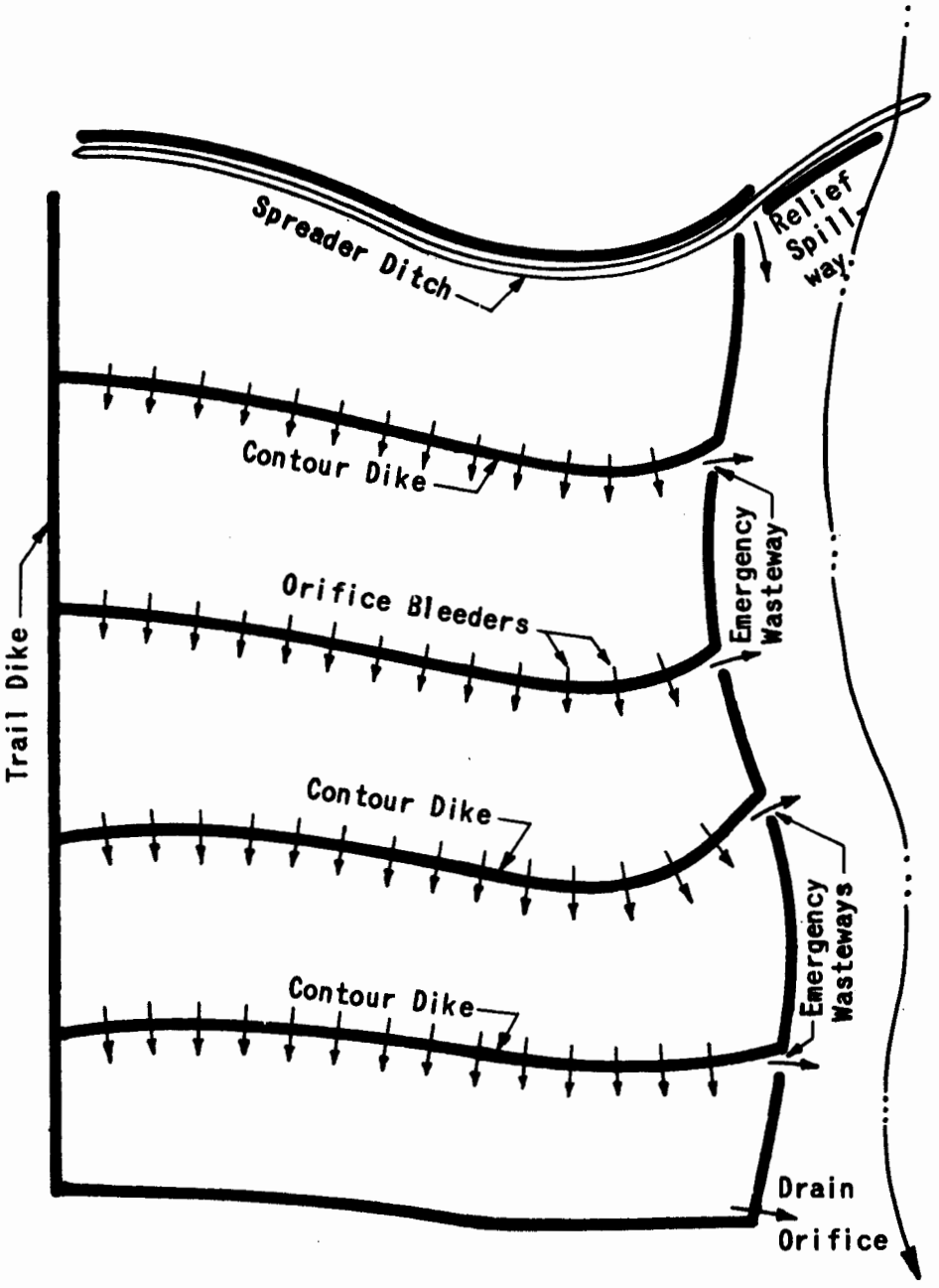


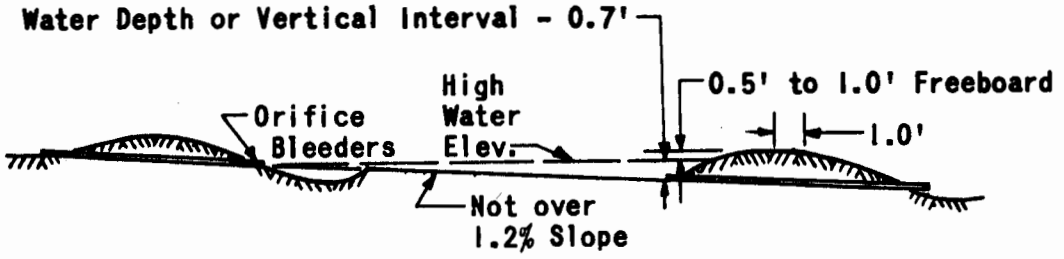
TYPE 2

TYPICAL DIKE WEIRS

Figure 14.8

DIKE AND BLEEDER WATER SPREADING SYSTEM





SECTION THRU DIKE AND BLEEDER

Figure 14.9

59M-82

3. DESIGN (CONT'D)

Detention Type Systems

Detention type systems rely on the impounding of water over the spreading area to increase the opportunity time for infiltration. Detention type systems require manual control when the desired application has been made. When only the upper dikes are filled from a storm, the excess water is sometimes used in the diked areas below and little or none is wasted from the area.

Detention systems are quite efficient because control of the water is provided and the depth of water application is not dependent upon the duration of flow. The principal disadvantage is that management is needed since they are not completely automatic in nature. On the tighter soils, or those on which the water intake rate is low, a detention type system should be used to hold the needed amount of water until it can enter the ground. These systems are adapted to ground slopes of 2 percent or less. At a maximum slope of 2 percent, the usual procedure is to use 2.0 feet high dikes at a spacing of 75 feet, which provides a 0.5 foot freeboard and 1.5 feet of water at the lower dike and zero water at the upper dike, or an average depth of 9 inches halfway between the dikes. This is not a very uniform spread of water by irrigation standards, but represents maximum spacings for best results. Increasing the spacing or height of spreader ditches and dikes decreases the uniformity of the water distribution. Decreasing the spacing makes construction costs higher but provides better water spreading. In some cases, the system can be modified whereby ponding is only provided on the lower one-half or two-thirds of the detention basin utilizing overland flows to irrigate the upper portion of the intervening area.

Manual Inlet Control Systems. Manual inlet control systems are adapted for use when long duration flows are expected. They are particularly adapted for use when snow melt is the important source of water.

In these systems, as shown by Figure 14.10, the floodwaters are diverted out of the dry draw by a base grade diversion or dam. The spreader ditches and dikes are constructed as given in the detail on Figure 14.7. The supply ditch is laid out to carry water down the slope at a nonerosive velocity and to convey water to each diked area. A main supply ditch structure is needed as well as checks and turnouts for each area to be irrigated. These structures are shown in Figure 14.11.

DETENTION SYSTEM
Manual Control Type

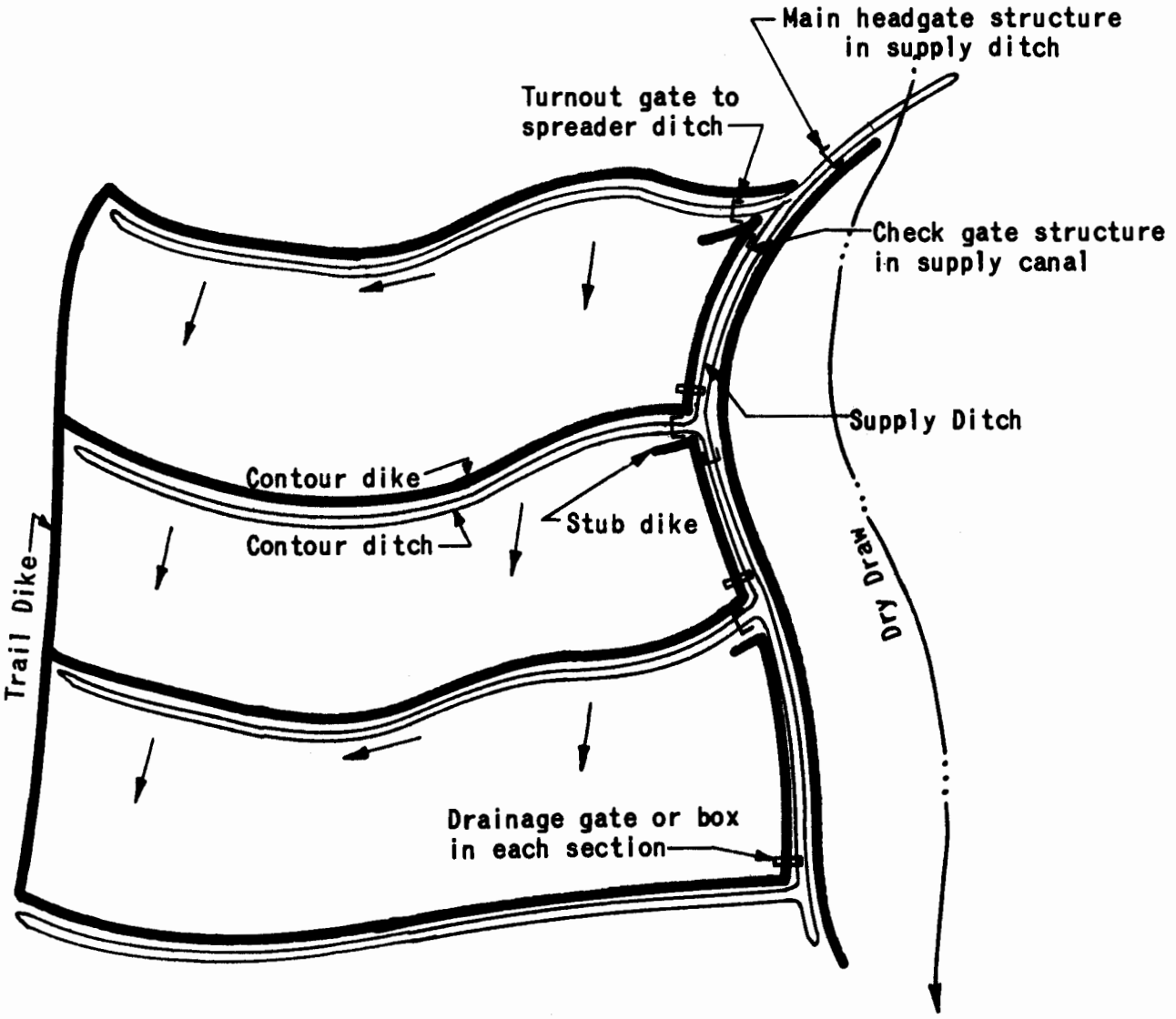
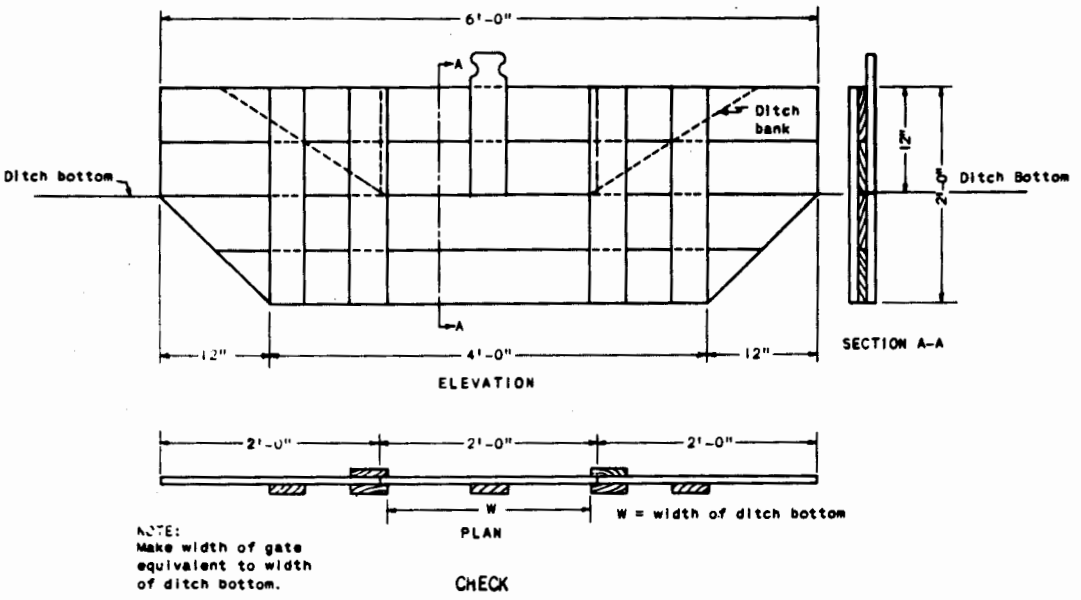
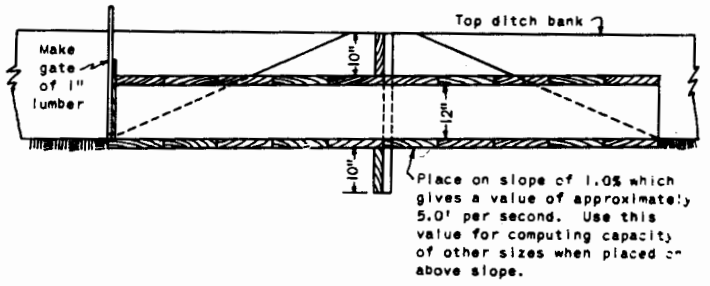
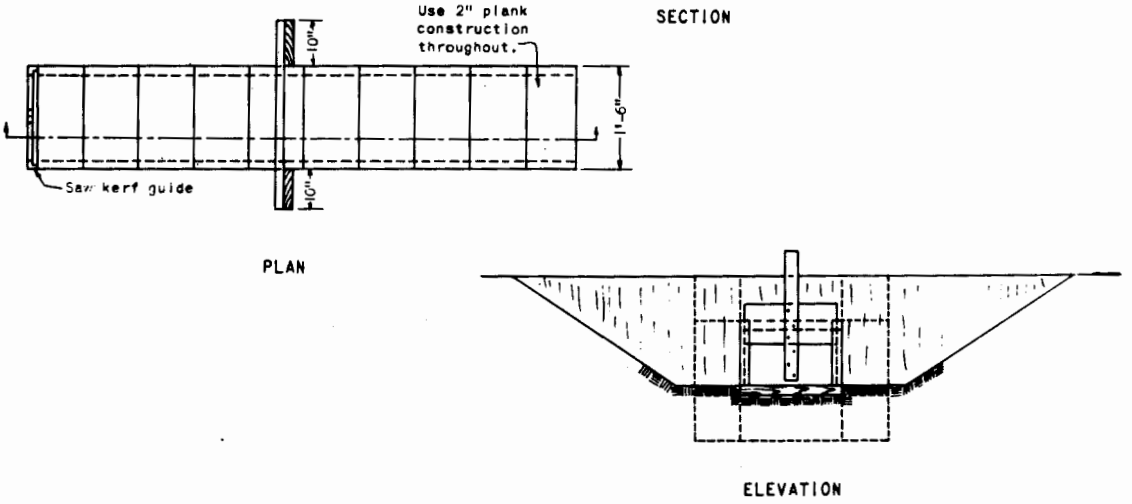


Figure 14.10

59M-82




Top ditch bank
Make gate of 1" lumber
10"
12"
10"
Place on slope of 1.0% which gives a value of approximately 5.0' per second. Use this value for computing capacity of other sizes when placed on above slope.
SECTION



TYPICAL CHECK, TURNOUT AND DRAINAGE STRUCTURES

This structure adapted for use on manually controlled system

59M-82

Figure 14.11

3. DESIGN (CONT'D)

Detention Type Systems (cont'd)

Automatic Inlet Control Systems. The automatic inlet control system has the advantage that it automatically fills when runoff occurs and the only manual control necessary is to drain the diked areas when the desired infiltration has taken place. In these systems, a metered flow is introduced through an orifice structure into each impounding area. The flow depth at the inlet is so designed that when the dike becomes full the back water prevents further diversion.

When the dry draw or watercourse is wide and shallow, each dike may be served from a separate diversion, and metered with an orifice structure. When the dry draw is deep, the metered flow may be carried by an artificial vegetated channel from which diversions are made. Such a system is shown in Figure 14.12.

This system will operate by itself if properly constructed and maintained. It should be considered for water spreading areas that are a considerable distance from the ranch headquarters.

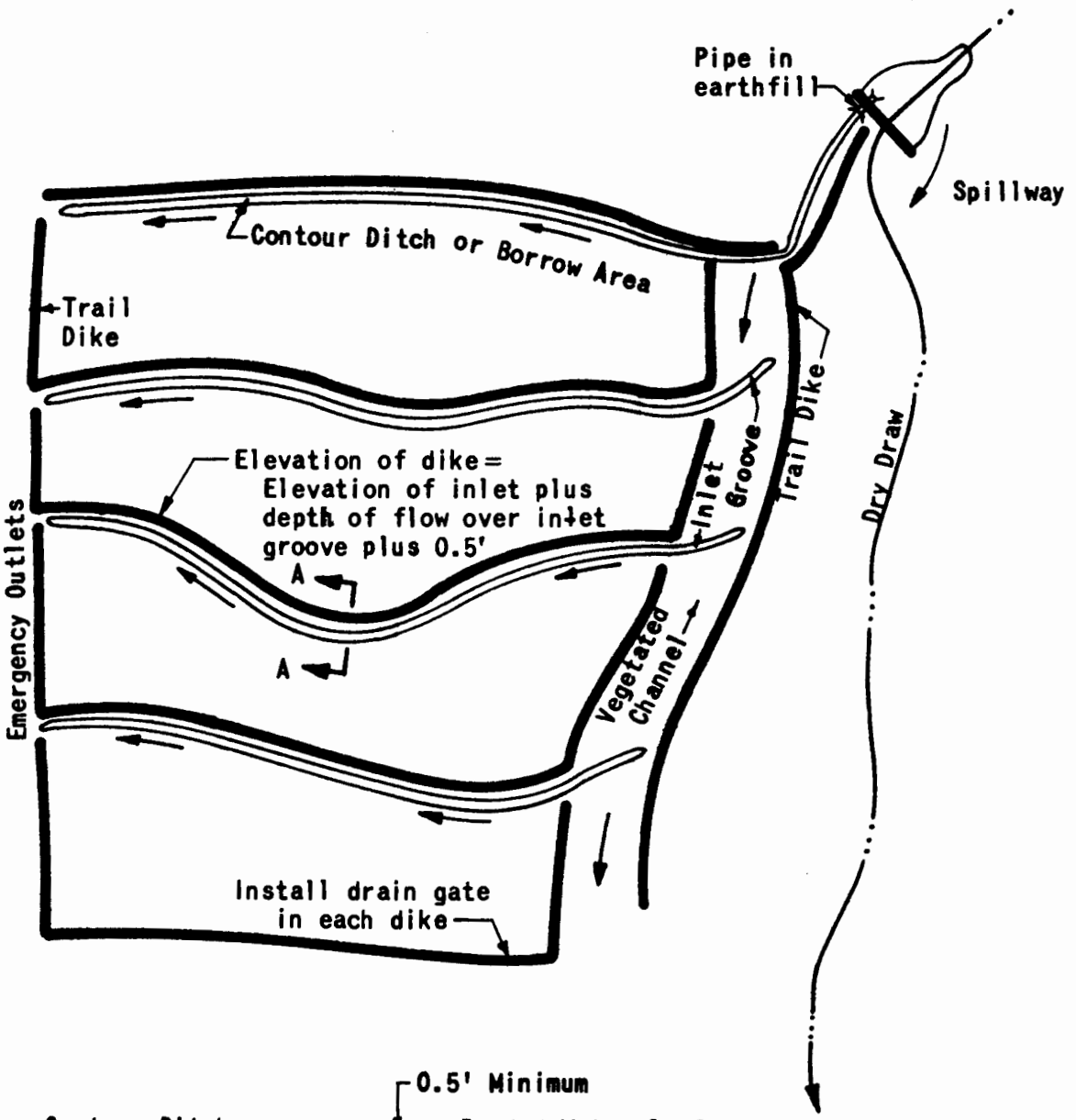
Automatic inlet control systems should be limited to slopes of 2 percent or less. The dike and spreader ditch construction is the same as described for the manual control type of detention systems. The spacing of dikes is also comparable. The vegetated channel must be designed to carry the diverted flow from the dam in a wide shallow manner for the best pickup performance by the inlet grooves.

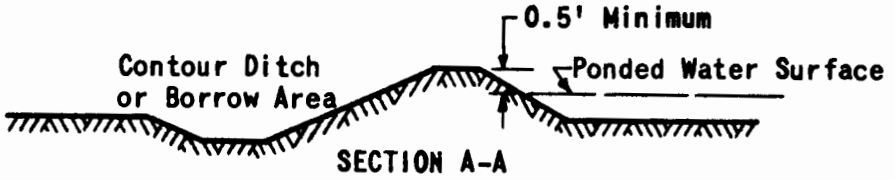
Example

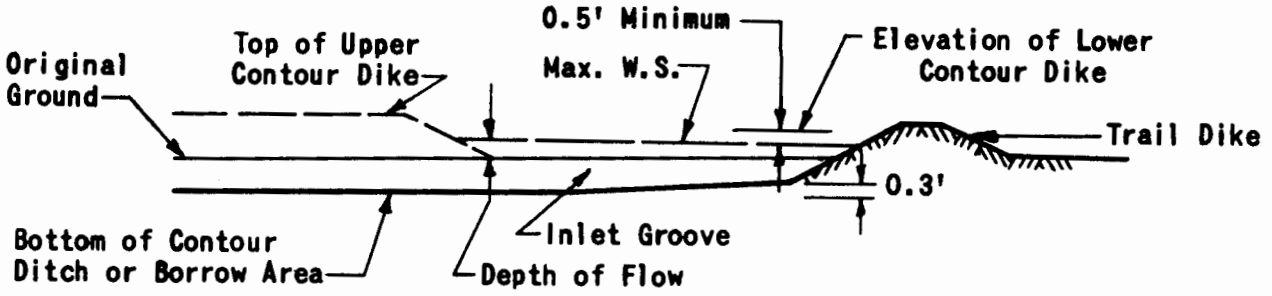
The following example shows in detail the calculations required for the hydrologic analysis of a water spreading system.

NOMENCLATURE:

- a = Spreading area, acres
- P_n = Design precipitation for n-year frequency storm, inches
- R = Runoff from design rainstorm, inches
- A = Drainage area, square miles
- T_c = Time of concentration, hours
- d_a = Design application depth, inches
- q = Unit peak discharge, cubic feet per second
- Q = Peak discharge, cubic feet per second
- Q_d = Diverted flow, cubic feet per second
- V_s = Storm runoff volume, acre inches
- V_d = Diverted volume, acre inches







DETAIL OF INLET GROOVE

Figure 14.12

59M-82

3. DESIGN (CONT'D)

Example (cont'd)

GIVEN:

Drainage area	A	= 6 sq. mi.
Time of concentration	T_c	= 1.77 hours
Maximum available size of water spreading area	a	= 140 acres
Soil cover complex no. of drainage		= 75
Expected storm rainfall		
5 yr - 20% chance	P_5	= 2.0 in.
2 yr - 50% chance	P_2	= 1.4 in.
1.25 yr - 80% chance = 0.8 x P_2 =	$P_{1.25}$	= 1.1 in.
Type of system		Flow type
Soil texture on spreading area	F	= Mod. Fine

SOLUTION:

(1) Determine the design storm runoff, R, for each rainfall frequency from Figure 3.5

(2) Compute the storm volume, V_s, from equation $V_s = 640\ AR$

(3) Determine the zone in which the project lies from Figure 3.6

(4) Determine the unit peak discharge, q, from Figure 3.7. For this example q = 227. cfs

(5) Compute the peak discharge, Q, for each storm frequency from the equation $Q = qAR$

(6) Determine the design application, d_a, from Figure 14.2

(7) Compute the maximum spreading area for each frequency $a = V_s/d_a$

(8) Tabulate the results thus

Class of System	% Chance	R inches	V_s ac. in.	Q cfs	d_a inches	a acres
Undependable	20%	0.38	1460	518	5.2	281
Questionable	50%	0.17	653	232	5.2	126
Dependable	80%	0.07	269	95	5.2	52

3. DESIGN (CONT'D)

Example (cont'd)

From this it can be seen that if the entire flood flow can be diverted there is a dependable supply for 52 acres, a questionable supply for 126 acres and an undependable supply for 281 acres.

Let us suppose that it was determined to divert a flow, Q_d, equal to the peak flow, Q, for a dependable system. This is 95 cfs.

(9) Determine the ratio, Q_d to Q

(10) From Figure 14.5, interpolate the values of r_v

(11) Compute the quantity of water diverted, V_d
$V_d = r_v V_s$

(12) Compute the area, a
$a = V_d/d_a$

(13) Tabulate the results thus

Class of System	Q cfs	Q_d cfs	Q_d/Q	r_v	V_s ac.in.	V_d ac.in.	d_a inches	a acres
Undependable	518	95	0.18	0.32	1460	467	5.2	90
Questionable	232	95	0.41	0.65	653	424	5.2	82
Dependable	95	95	1.00	1.00	269	269	5.2	52

From this it can be seen that if the quantity diverted is 95 cfs, 52 acres would have a dependable class system, a questionable supply for 30 additional acres and an undependable supply for still 8 acres more.

If it is desired to divert a different stream, say 50 cfs, the following calculations can be made:

Class of System	Q cfs	Q_d cfs	Q_d/Q	r_v	V_s ac.in	V_d ac.in.	d_a inches	a acres
Undependable	518	50	0.10	0.18	1460	263	5.2	51
Questionable	232	50	0.22	0.38	653	248	5.2	48
Dependable	95	50	0.53	0.78	269	210	5.2	40

This system would require a much smaller canal and yet would provide a dependable class system for 40 acres, a questionable class system for an additional 8 acres and an undependable system for another 3 acres. The entire 140 acres available would not be developed.

3. DESIGN (CONT'D)

Development of the Water Spreading Plan

Having designed the system to be used according to the site conditions, expected runoff, capacity of the main canal, application depth, and area to be flooded, a plan must be developed to show this information. The plan should include the point of diversion, location of all canals, spreader ditches, dikes and structures and how the excess water will be safely carried to a discharge point. Much of this information can be shown on the master plan, which may be an overlay of the original topographic map. Data sheets are needed to give essential information used in the design or calculations that were made.

4. LAYOUT

Other parts of this handbook describe the procedures to follow in setting line and grade stakes for construction. The system should be laid out so the contractor can construct it with only the layout plan, specifications, and structural plans for his direction.

5. CONSTRUCTION

Construction of a water spreading system entails principles of earth moving, embankment construction, and structural work. Specifications concerning this work are covered in other parts of this handbook and in practice specification guides. Specifications on each segment of the system should be furnished the contractor.

Water spreading system construction may require a variety of equipment. Adaptable earth moving equipment includes: draglines, crawler type tractor and carryall scrapers, compaction rollers, blade patrols, side elevating graders, and many others. Refer to other parts of this handbook for equipment necessary for construction of reinforced concrete, wood, rubble masonry, or metal structures.

A good bond is needed between the original ground and the earth in the dike. This can be done by stripping the base of vegetation or by plowing a few furrows. Fill material for dikes generally should be taken from the downhill side. The borrow pits should be broad and shallow. When construction is completed the dikes, ditches, borrow pits, and all disturbed areas should be seeded with an adaptable grass species. If plants on the area are desirable perennials, they should be disturbed as little as possible during construction operations.

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6. MAINTENANCE

Proper maintenance is essential on any water spreading system. It is helpful to observe the system in operation and to correct the defects that appear.

Some common maintenance problems include:

(1) Debris and silt deposits in control structures and canals.

(2) Erosion in canals and spreader ditches.

(3) Low spots in dikes caused by settling, overtopping, or wave action.

(4) Erosion of dike weirs.

(5) Plugging of pipe drains.

(6) Gullying of the channel which returns excess flows to the original channel.

Regular inspection and maintenance are necessary to insure proper operation and to correct deficiencies while they are small.

CONTENTS

PART 15

STRUCTURES

Subject	Page
1. General	15-1
Definition and Use	15-1
Design	15-1
2. Materials	15-1
Concrete	15-1
Wood	15-2
Metal	15-3
Masonry	15-3
Plastics	15-4
3. Construction Methods	15-4
Concrete Structures	15-4
Mixing	15-4
Placing	15-4
Curing	15-4
Forming	15-5
Joints	15-5
Wooden Structures	15-5
Metal Structures	15-6
Masonry Structures	15-6
Plastic Pipe	15-6
4. Maintenance	15-6
5. Equipment	15-7

PART 15

STRUCTURES

1. GENERAL

Definition and Use

Most conservation plans require one or more varieties of structure to control the flow of water and eliminate or reduce erosion. They usually are used only where vegetative means are impractical for that purpose. Structures are particularly important in areas of high intensity rainfall and in irrigated areas. They may be constructed of concrete masonry, wood, metal, or other approved materials depending on local conditions and the preference of the owner or technician. Structures vary in purpose and size, according to the need. Examples of structures are drops, chutes, headgates, siphons, flumes, drop inlets, and spillways. The conservation planner must know when to use each type of structure to its best advantage. He must also know some of the principles of construction in order to direct the installation of structures.

Design

Most requirements for structures planned by Soil Conservation Service personnel can be met with a structure of standard design.

Modifications in standard structures, such as extending or shortening wing walls and cutoffs to meet local conditions, may be made to a limited extent. Thickness of walls, location and quantity of steel, length of crest, etc., cannot be changed. Structures for which there is no suitable standard design shall be designed by a qualified engineer. An understanding of hydrostatic and lateral earth pressures, and other stresses, as well as design codes and criteria are necessary in order to design non-standard or "tailor-made" structures. The hydraulic design must also be such as to satisfy the functional requirements. Complete detailed drawings of non-standard structures are required for a permanent record.

2. MATERIALS

Concrete

Concrete used for structures should consist of a correct mixture of sand and gravel, or crushed stone, cement and water as covered by the standard specifications for concrete.

Technicians who are doing considerable work with concrete will find the following publications of great value: "Concrete Manual", USDI, Bureau of Reclamation; "Design and Control of Concrete Mixture", published by Portland Cement Association.

2. MATERIALS (CONT'D)

Concrete (cont'd)

Structures made of good concrete have the properties of strength, rigidity, long life, non-erosiveness, and fire resistance.

Good concrete is high in compressive strength or its ability to resist crushing. It is relatively weak in tensile strength or its ability to resist bending. It is normally necessary to combine reinforcing steel with concrete to overcome its weakness in tension.

External forces caused by earth or water pressures, dead load of the structure itself and expansion and contraction due to temperature, cause tensile stresses in concrete structures.

Concrete structures to be located in areas of highly concentrated alkali salts require special consideration. In such areas of "hot" soils, or in areas where the water is strongly alkaline, it is necessary to use Type V cement in the concrete mixture. In areas where concentrations of these corrosive salts are moderate, Type II cement should be used.

The use of thin-wall concrete structures, such as ditch lining and concrete pipe, in areas of highly concentrated alkali salts should be avoided. Where structures have intermittent flows or have surfaces exposed to the weather, consideration should be given to the use of air entrained concrete.

Where a large volume of concrete is to be poured, such as a large structure or an extensive length of ditch lining, the mix should be carefully designed and tested to meet the needs of strength, durability, and water tightness. No additives should be used to prevent freezing.

When only a small quantity of concrete is to be placed, such as that needed for five one foot irrigation drops, additional cement may be used to insure strength and durability rather than going to the expense of testing the concrete mixture. Aggregates of known characteristics are used whenever possible.

Wood

Wooden structures, especially those which have been treated with a preservative as set forth under the specifications for this section of the handbook are satisfactory.

In areas where treated lumber may be purchased locally and alkali is a serious problem, wooden structures may have an advantage over other materials. Wooden structures may be prefabricated and are easily and simply installed as compared to building forms for a concrete structure. They are relatively inexpensive, do not crack, and are not subject to deterioration by alkali salts. Structures made of wood are subject to destruction by fire, termites, and rot. These hazards usually make wood

2. MATERIALS (CONT'D)

Wood (cont'd)

structures relatively short lived as compared to concrete. A structure of well preserved wood normally should last from 10 to 20 years, depending on the kind of wood and type of treatment used.

Metal

Structures made of metal have the advantage of being prefabricated by the manufacturer so that the user is confronted only with the problems of installing and preserving it. Flumes, siphons, Parshall flumes and weirs, pipe drop structures, pipe drop inlets, alfalfa gates, turnouts, and slide gates, are examples of metal structures used frequently in irrigated areas. Catalogs published by the manufacturer describe the operating conditions under which most of these structures are used. Also included are specifications, accessories, and tips on installation. Parshall flumes should be made of galvanized steel or of heavy steel plate that is treated with a protective coating.

Asphalt is used extensively for waterproofing and as a hot-dip coating for metal pipe. As a hot-dip material, it is better adapted for factory application. For field application, cold-applied cold-tar paints are used. They must be applied in relatively thin coats, thus a number of applications must be made to build up film thickness comparable to that obtained with hot coatings. Coal-tar emulsions should not be used as a protective coating for submerged metal work. Red lead prime coats covered with aluminum paint are satisfactory for small gates and other alternately exposed and submerged metalwork of canal structures. Methods of protective coatings for metal structures are set forth under the specifications for this section of the handbook.

Masonry

Native rock or precast concrete block masonry is sometimes used for structures where low cost of materials is of primary importance. The use of such material is limited to small, low structures where tensile strength is not required. These structures should be confined to site locations having well drained foundation conditions to avoid breaking up by frost action.

Precast block construction is limited to blocks made of concrete. Other blocks made of cinders or pumice stone are very permeable and may cause saturation of the surrounding earth and ultimate failure due to piping of water flow under and around the structure.

2. MATERIALS (CONT'D)

Plastics

For certain types of structures, such as pipe lines, plastics are coming into use. Plastic pipe can be the answer where corrosive soil conditions prohibit the use of metal or where the danger of failure through freezing of flow cannot otherwise be overcome.

3. CONSTRUCTION METHODS

Concrete Structures

The use of concrete in structure work can result in a satisfactory or an unsatisfactory product, depending upon the degree of attention and planning given to the basic principles of construction.

Mixing. After a correct design of concrete mixture has been determined it is necessary to convert the dry ingredients to a plastic state for final placement. Normally, this mixing operation is achieved by a power driven mixer consisting of a rotating drum. The dry ingredients, cement, sand and gravel, should be mixed thoroughly before addition of the water. Mixing action should not be less than 1¼ minutes of time. Small quantities of concrete are sometimes mixed by hand on a large mixing board or in a box. The same general principles are followed when using this method as when using a mechanical mixer. The dry ingredients are mixed first by turning with shovels. The water is then added to a crater formed in the dry mixture after which mixing continues by folding dry material into the water.

If special additives such as air entraining agents are used, they should be placed in the mixture at the same time or immediately after all the water is added. Air entraining agents are often included in the cement when manufactured.

Placing. Concrete should be placed as closely as possible to its final position. If placed in large quantities at a given point and worked over a long distance in the form, segregation of materials will result. Concrete should be placed in horizontal layers from 6 inches to 12 inches thick for reinforced members and up to 18 inches thick for mass work. Concrete must not be dropped freely through reinforcing or against forms from heights greater than 5 feet. After placement, concrete should be vibrated, spudded, or otherwise compacted to remove entrapped air.

Curing. Concrete must be protected so that moisture is not lost during the early stages of hardening. It must be kept at a temperature that will promote hydration. It can be kept moist by leaving forms in place, sprinkling and ponding, use of moisture retention covers such as burlap or cotton quilts, well moistened backfill, and curing compounds. In hot weather, precautions must be taken to avoid high temperatures in the fresh concrete and to avoid rapid drying. Subgrades should be saturated some time in advance and sprinkled just ahead of the placing operation. Concrete

3. CONSTRUCTION METHODS (CONT'D)

Concrete Structures (cont'd)

Curing (cont'd)

should never be placed on a frozen subgrade. Concrete must be protected from low temperatures by heating the water or the aggregate or both, and protecting it after it is in place. The air surrounding fresh concrete should be maintained at 50 degrees F. or above for the first five days for best results.

When cracks appear in concrete structures they should be sealed with mastic type joint sealing compound. This compound is usually applied with calking equipment or a trowel. Joints should be clean and the surface dry before filling from bottom to top.

Forming. Forms must be strong enough to support the concrete while it is plastic and to carry the live loads incidental to the construction operation. They must be securely placed and braced so as to give true finished dimensions and surfaces to the concrete. Spacer blocks are used to hold the faces the required distance apart. Ties are used to prevent the forms from spreading while being filled. Several form ties have been developed which permit removal of a portion of the ties for a depth of one to two inches from the surface. The holes are patched upon removal of the forms.

Joints. The junction of two successive concreting operations in members intended to act monolithically is called a construction joint. Construction joints should be located in regions of low shear and low bending moment. They are used when the job cannot be completed without stopping the operation of pouring the concrete. Joints should be made straight, exactly horizontal or exactly vertical. When the fresh concrete is placed on the hardened concrete, the hardened concrete should be clean, moist, free of laitance, and reasonably rough.

Wooden Structures

In general, small wooden structures are constructed and assembled before being placed in final position of use. However, if a structure is too large or heavy to handle easily it may be constructed in sections or panels and assembled in final position by joining the component sections in their proper place.

Wherever facilities permit, the individual pieces making up a wooden structure should be treated with the specified preservative after all saw cuts and shaping have been made. This eliminates unprotected ends which result if a previously treated piece is cut. Pressure treatment of wood structures should be given preference over other methods of preservative application.

3. CONSTRUCTION METHODS (CONT'D)

Wooden Structures (cont'd)

All lumber shrinks or swells to some degree when exposed to alternate wetting and drying. Cracks between individual boards of a wooden structure cause leakage and may start piping around the structure. This can be overcome by use of batting strips on plain lumber or by use of tongue and groove lumber.

Metal Structures

Metal structures are normally made by professional fabricators and present no problems in themselves. Care must be taken to see that all surfaces of metal structures are covered with the specified protective coating before installation. Extra care must be taken in thoroughly compacting earth backfill around smooth metal surfaces to prevent hydraulic piping.

Masonry Structures

Masonry construction frequently presents problems of structure failure due to foundation movement through settlement or frost heaving. Earth foundations must be thoroughly compacted before placing masonry structures. Rocks and stones used in rubble masonry should be placed in a bed of mortar. Masonry should seldom be constructed by first placing a layer of rock and then attempting to fill the void spaces with mortar. This procedure without special measures results in a weak and poorly bound slab.

Construction of low vertical walls with rubble masonry is usually accomplished by hand placed mortared joints, the same as in bricklaying.

Concrete block structures should be placed on a foundation of previously poured concrete. The concrete blocks should be thoroughly wetted immediately before use to secure a good bond and to avoid dehydration of mortar.

Plastic Pipe

Installation of plastic pipe and fittings should be made in accordance with the manufacturer's directions and recommendations.

4. MAINTENANCE

All structures need maintenance to prolong their life and thus reduce replacement cost. Owners should be urged to inspect structures at least once annually and at other opportune times. Cracks that develop should be sealed, protective coatings applied where needed, and modifications, riprap or repairs made where and when they are necessary. Often a small repair job will prevent a large repair job or even complete failure later on.

5. EQUIPMENT

Equipment needed for most small structures constructed by farmers or ranchers is simple. Hand tools such as hammers, saws, picks and shovels, concrete mixer, and facilities for hauling materials and barrels for water are necessary. Where anything more than very simple forming is required, a carpenter is necessary to build and set the forms correctly. Where a large number of small irrigation structures are contemplated, it is wise to build a set of steel forms that can be used repeatedly and will greatly speed the work. Forms or templates can be made for ditch lining, however, metal slip forms are recommended where there is any appreciable amount of ditch lining.

Larger structures require heavy equipment not available to farmers. Such jobs are usually constructed under contract by a contractor.

CONTENTS

PART 16

HYDRAULICS

Subject	Page
1. General	16-1
Introduction	16-1
2. Open Channel Flow	16-1
Definition	16-1
Open Channel Formulas	16-1
Example of Open Channel Flow Determination	16-3
Limitations	16-13
Critical Flow	16-13
Flow in Open Channel Spillways	16-13
3. Weir Flow	16-24
Definition	16-24
Use and Limitations	16-25
Cippoletti and Triangular Notch Weirs	16-25
The Parshall Flume	16-30
4. Orifice Flow	16-39
Definition	16-39
Flow of Water Through Gates	16-39
5. Pipe Flow	16-40
Definition	16-40
Pipe Friction	16-41
Flow of Water in Small Pipes	16-41
Flow Through Outlets or Culverts	16-53
Design of Inverted Siphons	16-58
Closed Conduit Spillways	16-60
Definition	16-60
Materials	16-60
Drop Inlet Spillways	16-60
Capacity of Drop Inlet Spillways	16-60
Example of Drop Inlet Flow Determination	16-62
The Hood Inlet	16-71
Corrugated Metal Pipe Arches	16-81

LIST OF FIGURES

PART 16

HYDRAULICS

Figure Number	Title	Page
16.1	Graphic Solution of Manning's Formula	16-2
16.2	Example of Open Channel Cross Section	16-3
16.3-1	Values of Roughness Coefficient, n	16-5
16.3-2	Values of Roughness Coefficient, n (cont.)	16-6
16.4-1	Irrigation Ditch Sections with Required Lateral Beds	16-7
16.4-2	Discharge Capacity of Canals	16-8
16.4-3	Discharge Capacity of Canals	16-9
16.4-4	Discharge Capacity of Canals	16-10
16.4-5	Discharge Capacity of Canals	16-11
16.5	Safe Velocities - Open Channel Flow in Erodible Material	16-14
16.6-1	Head Discharge Curves for One-Foot Width of Emergency Spillway	16-16
16.6-2	Head Discharge Curves for One-Foot Width of Emergency Spillway	16-17
16.6-3	Head Discharge Curves for One-Foot Width of Emergency Spillway	16-18
16.6-4	Head Discharge Curves for One-Foot Width of Emergency Spillway	16-19
16.6-5	Head Discharge Curves for One-Foot Width of Emergency Spillway	16-20
16.6-6	Head Discharge Curves for One-Foot Width of Emergency Spillway	16-21
16.7-1	Relation of Discharge to Depth at the Control Section of Emergency Spillways	16-22
16.7-2	Relation of Discharge to Velocity at the Control Section of Emergency Spillways	16-22
16.8	Cippoletti Weir	16-25
16.9	V-Notch or Triangular Weir	16-25
16.10	Cross Section of Typical Weir Crest	16-25
16.11-1	Discharge Table for Cippoletti Weirs with Complete Contractions	16-26
16.11-2	Discharge Table for Cippoletti Weirs with Complete Contractions (cont.)	16-27
16.11-3	Discharge Table for Cippoletti Weirs with Complete Contractions (cont.)	16-28
16.12	Discharge Table for 90° Triangular Notch Weirs with Complete Contractions	16-29
16.13	Section of Parshall Measuring Flume	16-31

Figure Number	Title	Page
16.14-1	Free Flow Through Small Parshall Measuring Flume	16-32
16.14-2	Free Flow Discharge Table for Parshall Flumes	16-33
16.14-3	Free Flow Discharge Table for Parshall Flumes	16-34
16.14-4	Free Flow Discharge Table for Parshall Flumes	16-35
16.14-5	Free Flow Discharge Table for Parshall Flumes	16-36
16.14-6	Free Flow Discharge Table for Parshall Flumes	16-37
16.15	Table Showing Minimum Head Loss Through a Parshall Flume with Free Flow Conditions	16-38
16.16	Typical Cross Section, Submerged Gate	16-39
16.17	Coefficient of Discharge "C" for Submerged Gates	16-40
16.18	Velocity Heads and Entrance Heads for Pipe in Feet of Water	16-42
16.19	Resistance of Valves and Fittings in their Equivalent Length of Straight Pipe, in Feet	16-43
16.20-1	Friction Loss in Small Diameter Pipe	16-44
16.20-2	Head Loss in Feet per Thousand Feet Concrete Pipe with Mortar Joints	16-45
16.20-3	Head Loss in Feet per Thousand Feet Concrete Pipe with Concentric Gasket Joints	16-46
16.20-4	Head Loss in Feet per Thousand Feet Plastic Pipe	16-47
16.20-5	Head Loss in Feet per Thousand Feet Smooth Interior Corrugated Metal Pipe	16-48
16.20-6	Head Loss in Feet per Thousand Feet Inside Lined Welded Steel Pipe	16-49
16.20-7	Head Loss in Feet per Thousand Feet Inside Lined Welded Steel Pipe (cont.)	16-50
16.20-8	Head Loss in Feet per Thousand Feet Unlined Welded Steel Pipe	16-51
16.20-9	Head Loss in Feet per Thousand Feet Unlined Welded Steel Pipe	16-52
16.21	Typical Small Pipe Installation	16-53
16.22	Coefficients of Discharge "C" for Culverts	16-54
16.23	Typical Cross Section of Culvert	16-55
16.24	Capacity of Smooth Pipe Culverts - Free Outlet	16-56
16.25	Capacity of Corrugated Pipe Culverts - Free Outlet	16-56
16.26	Capacity of Corrugated Pipe Culvert - Submerged Outlet	16-57
16.27	Typical Inverted Syphon Cross Section	16-58
16.28	Loss of Head on Elbows	16-59
16.29	Friction Head Loss in Corrugated Metal Pipe	16-59
16.30	Cross Sections of Head Discharge Conditions Drop Inlet Spillways	16-61
16.31	Typical Drop Inlet Cross Section	16-62
16.32	Head Discharge - Corrugated Metal Pipe Weir Flow Condition	16-63
16.33-1	Head Discharge - Corrugated Metal Pipe Orifice Flow Condition (Part 1)	16-64
16.33-2	Head Discharge - Corrugated Metal Pipe Orifice Flow Condition (Part 2)	16-65

Figure Number	Title	Page
16.34-1	Head Discharge - Corrugated Metal Pipe Full Pipe Flow Condition	16-66
16.34-2	Head Discharge - Corrugated Metal Pipe Full Pipe Flow Condition	16-67
16.35-1	Head Discharge - Corrugated Metal Pipe Small Diameters	16-68
16.35-2	Head Discharge - Corrugated Metal Pipe Small Diameters (cont.)	16-69
16.36	Cross Section - Simple Hood Inlet	16-71
16.37	Diameter of Riprap and Radius of Scour for Hood Inlets	16-73
16.38	Typical Hood Inlet Installation	16-74
16.39-1	Head Discharge Tables for Corrugated Metal Pipe Hood Inlets - Full Pipe Flow Conditions (For Irrigation)	16-75
16.39-2	Head Discharge Tables for Corrugated Metal Pipe Hood Inlets - Full Pipe Flow Conditions (For Dams)	16-76
16.39-3	Head Discharge Tables for Corrugated Metal Pipe Hood Inlets - Full Pipe Flow Conditions (For Dams) (cont.)	16-77
16.40-1	Head Discharge Tables for Welded Steel Pipe Hood Inlets - Full Pipe Flow Conditions (For Irrigation)	16-78
16.40-2	Head Discharge Tables for Welded Steel Pipe Hood Inlets - Full Pipe Flow Conditions (For Dams)	16-79
16.40-3	Head Discharge Tables for Welded Steel Pipe Hood Inlets - Full Pipe Flow Conditions (For Dams) (cont.)	16-80
16.41	Typical Cross Section of Pipe Arches	16-81
16.42	Details of Corrugated Metal Pipe Arches	16-82
16.43	Full Flow Velocities in Ft./Sec., for Arched Corrugated Metal Pipe	16-83
16.44	Friction Loss in Feet (H_f) per Lineal Feet of Arched Corrugated Metal Pipe	16-84
16.45	Entrance and Velocity Head Loss for Full Pipe Flow in Arched Corrugated Metal Pipe	16-85

PART 16

HYDRAULICS

1. GENERAL

Introduction

The purpose of this section is to provide Work Unit Staffs with sufficient reference to fundamentals, formula and tables of hydraulics that the more simple problems of open channel flow, weir flow, orifice and pipe flow may be solved by persons not especially trained in engineering. For the more complicated hydraulic problems, it is taken for granted they will be referred to engineers for solution. A more complete and detailed expansion of the material presented in this section may be found in Section 5, "Hydraulics", National Engineering Handbook or "Handbook of Hydraulics", by H. W. King.

As a means of simplifying mathematics and providing many of the coefficient needed to solve hydraulic equations, various tables and nomographs have been developed. Such material appropriate for the scope of this section have been included or referred to in other publications.

2. OPEN CHANNEL FLOW

Definition

An open channel is any conduit in which water flows with a free surface. Pipes and tubes are classed as open channels when flowing partially full. The basic formula involving flow is:

$$Q = av$$ where:

Q = Quantity of water discharged in cubic feet per second (c.f.s.).

a = Cross-sectional area of the stream carried by the channel in square feet.

v = Velocity of flow in feet per second.

Open Channel Formulas

Many studies and evaluations regarding open channel flow have been made, As a result of this work, many empirical formulas have been developed for the solution of open channel flow. For the purposes of this part of the handbook, only one of these will be covered. This open channel formula is known as "Manning's Formula", and was developed by Robert Manning in the year 1890. It is expressed as follows:

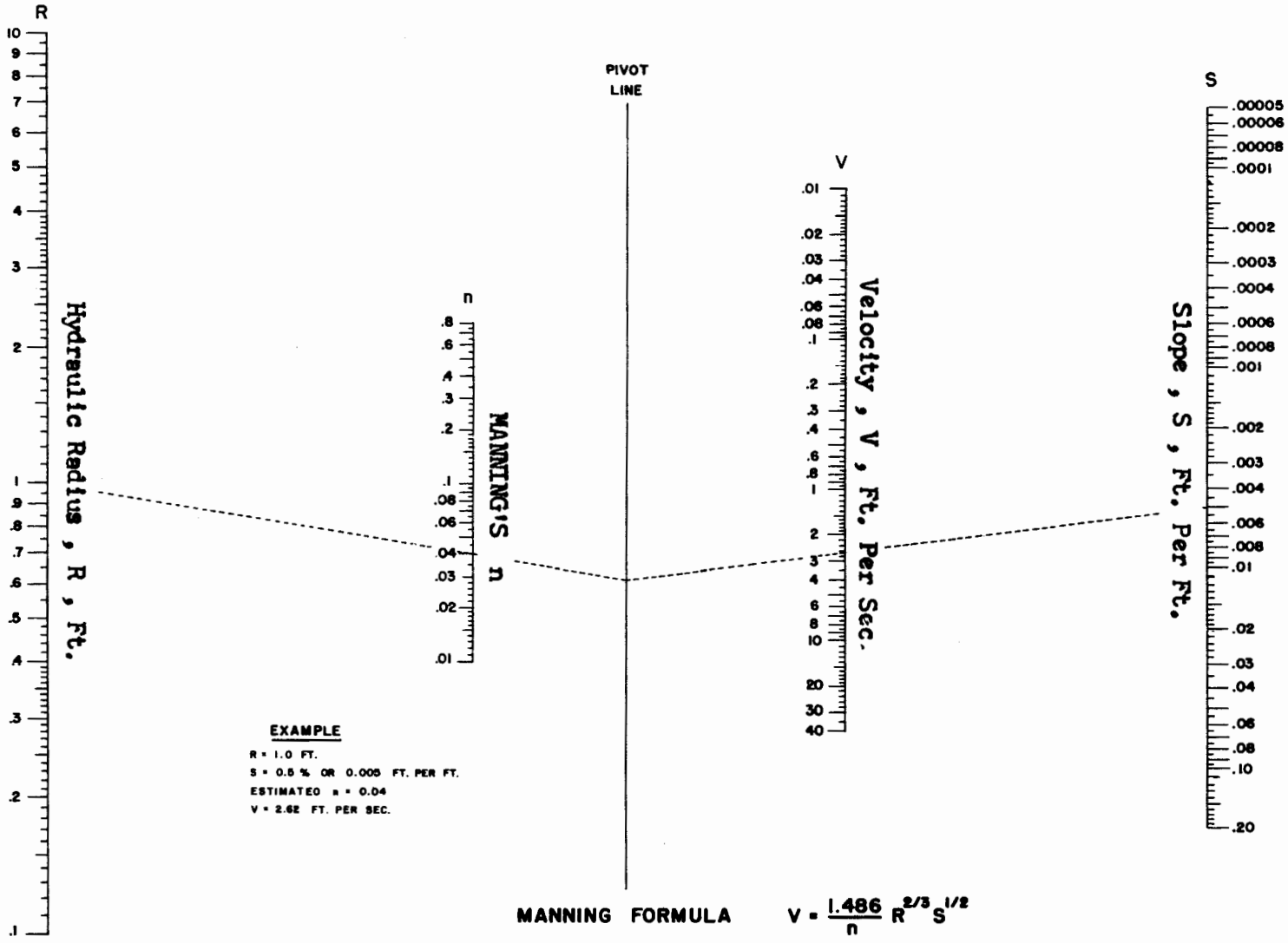
R
Hydraulic Radius , R , Ft.
n
MANNING'S n
PIVOT
LINE
V
Velocity , V , Ft. Per Sec.
S
Slope , S , Ft. Per Ft.
EXAMPLE
R = 1.0 FT.
S = 0.5 % OR 0.005 FT. PER FT.
ESTIMATED n = 0.04
V = 2.62 FT. PER SEC.
MANNING FORMULA V = 1.486/n R^2/3 S^1/2

Figure 16.1

2. OPEN CHANNEL FLOW (CONT'D)

Open Channel Formulas (cont'd)

$$\text{Manning Formula:} \quad v = \frac{1.486}{n} r^{2/3} s^{1/2}$$

Where: (v) is the velocity of flow in feet per second.

(n) is a coefficient of roughness of the channel. Figures 16.3-1 and 2 give values of "n" for various channel conditions.

(r) is the hydraulic radius. The hydraulic radius of a conduit is the area of a cross-section of the channel at the depth of the stream which it carries divided by the wetted perimeter. The wetted perimeter (p) is the length along the wetted sides and bottom of the cross-section. All units are in terms of feet.

$$r = \frac{a}{p}$$

(s) is the slope. It is the slope of the water surface, and under conditions of uniform flow is the same as the grade of the channel, in steep sections. The value of "s" is expressed in feet of fall per foot of length of channel.

The solution of this formula is not simple and is frequently solved by use of tables or graphs.

Figure 16.1 is a chart developed for the solution of Manning's Formula. Tables applicable to the solution of channel flow can be found in Hydraulic Tables, by the Corps of Engineers, U. S. Army. Discharge capacities of canals for a limited range of cross-sectional areas are given in Figures 16.4-1 through 5.

In the solution of Manning's Formula by any means, care must be exercised in selecting the coefficient of roughness "n" since an erroneous value can greatly affect the resulting computed velocity and quantity of flow. For purposes of designing, it is suggested that intermediate values of Figures 16.3-1 and 2 be used. When in doubt as to proper selection, an engineer should be consulted.

Example of Open Channel Flow Determination. The solution of the following example is presented for the conditions stated in Figure 16.2. Determine the capacity (Q) in c.f.s., for the following ditch:

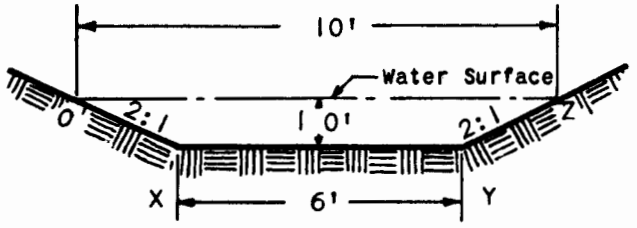

Figure 16.2

2. OPEN CHANNEL FLOW (CONT'D)

Open Channel Formulas (cont'd)

Example of Open Channel Flow Determination (cont'd)

Bottom width		6 feet
Side slopes		2:1
Depth of flow		1 foot
Coefficient (n)		0.03
Slope 0.3 foot per 100 feet	= $\frac{0.3}{100}$	= .003 ft. per ft.

Solution by use of Hydraulic Table (Corps of Engineers):

From the Tables, it is found that a ditch having the given dimensions, has an area of 8 sq. ft., and a hydraulic radius of 0.76. From the Tables, for an "n" value of 0.03 and a slope of "s" of .0030, the velocity corresponding to an "r" value of 0.80 is 2.34. By interpolation:

$$0.80 - 0.60 = 0.20;\quad 2.34 - 1.93 = 0.41;\quad 0.76 - 0.60 = 0.16$$

$$v = \frac{0.16}{0.20} \times 0.41 + 1.93 = 2.26 \text{ ft. per sec.}$$

then: $Q = av = 8 \times 2.26 = 18.1$ c.f.s.

Solution by use of mathematical computation:

a, the area of the cross section is:

$$\frac{6 \text{ ft.} + 10 \text{ ft.}}{2} \times 1 \text{ ft.} = 8 \text{ sq. ft.}$$

p, the wetted perimeter of Figure 16.2 is obtained as follows:

Lengths OX and YZ form the side slopes of the cross section and are equal to each other.

The length OX (or YZ) may be obtained by solving for the dimensions of a right triangle formed by the side slope, the water surface and an imaginary vertical line extended upward to the water surface from point X or Y. The dimensions of these legs of the right triangle are determined by the horizontal and vertical ratio of the given slope. By applying the geometric theorum that the square of the hypotenuse (OX or YZ) of a right triangle is equal to the sum of the squares of the other two sides of the triangle, the following results are obtained:

VALUES OF ROUGHNESS COEFFICIENT, n

Type of Conduit and Description	Values of n			References
	Min.	Design	Max.	
Pipe				
Cast-iron, coated	0.010	0.012 - 0.014	0.014	1
Cast-iron, uncoated	0.011	0.013 - 0.015	0.015	1
Wrought iron, galvanized	0.013	0.015 - 0.017	0.017	1
Wrought iron, black	0.012		0.015	1
Steel, riveted and spiral	0.013	0.015 - 0.017	0.017	1
Corrugated	0.021	0.025	0.0255	2
Wood stave	0.010	0.012 - 0.013	0.014	1
Neat cement surface	0.010		0.013	1
Concrete	0.010	0.011 - 0.017	0.017	1,6
Vitrified sewer pipe	0.010	0.013 - 0.015	0.017	1
Clay, common drainage tile	0.011	0.012 - 0.014	0.017	1
Lined Channels				
Metal, smooth semicircular	0.011		0.015	1,5
Metal, corrugated	0.0228	0.025	0.025	2
Wood, planed	0.010	0.012	0.015	1,5
Wood, unplaned	0.011	0.013	0.015	1,5
Neat cement-lined	0.010		0.013	1,5
Concrete	0.012	0.014 - 0.016	0.018	1,5
Cement rubble	0.017		0.030	1,5
Vegetated, small channels, shallow depths				
Bermuda grass; long - 13", green	0.042			3
Long - 13", dormant	0.035		0.28	3
Short - 3", green	0.034			3
Short - 3", dormant	0.034			3
Sericea Lespedeza; long - 16", green	0.076		0.22	3
Long - 16", dormant	0.050			3
Short - 2", green	0.033			3
Short - 2", dormant	0.034			3
Unlined Channels				
Earth; straight and uniform	0.017	0.0225	0.025	1
Dredged	0.025	0.0275	0.033	1
Winding and sluggish	0.0225	0.025	0.030	1

Figure 16.3-1

VALUES OF ROUGHNESS COEFFICIENT, n (CONT'D)

Type of Conduit and Description	Values of n			References
	Min.	Design	Max.	
Unlined Channels (cont'd)				
Earth; straight and uniform (cont'd)				
Stony bed, weeds on bank	0.025	0.035	0.040	1
Earth bottom, rubble sides	0.028	0.030 - 0.033	0.035	1
Rock cuts; smooth and uniform	0.025	0.033	0.035	1
Jagged and irregular	0.035		0.045	1
Natural Streams				
(1) Clean, straight banks, full stage, no rifts or deep pools	0.025		0.033	1,4
(2) Same as (1) but more weeds and stones	0.030		0.040	1,4
(3) Winding, some pools and shoals, clean	0.033		0.045	1,4
(4) Same as (3), lower stages, more ineffective slopes and sections	0.040		0.055	1,4
(5) Same as (3), some weeds and stones	0.035		0.050	1,4
(6) Same as (4), stony sections	0.045		0.060	1,4
(7) Sluggish reaches, rather weedy, very deep pools	0.050		0.080	1,4
(8) Very weedy reaches	0.075		0.150	1,4

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1. "King's Handbook", pp. 182 and 268.
2. "Hydraulics of Corrugated Metal Pipes", by H. M. Morris, St. Anthony Falls Hydraulic Laboratory, University of Minnesota.
3. Flow of Water in Channels Protected by Vegetative Linings", by W. O. Ree and V. J. Palmer; and USDA Technical Bulletin No. 967, February 1949.
4. "Low Dams", by National Resources Committee, U. S. Government Printing Office, Washington, D. C., pp. 227-233.
5. "The Flow of Water in Flumes", by Fred C. Scobey; USDA Technical Bulletin No. 393, Dec. 1933.
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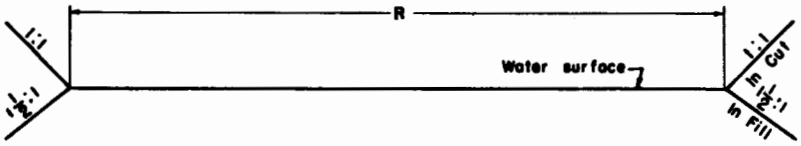
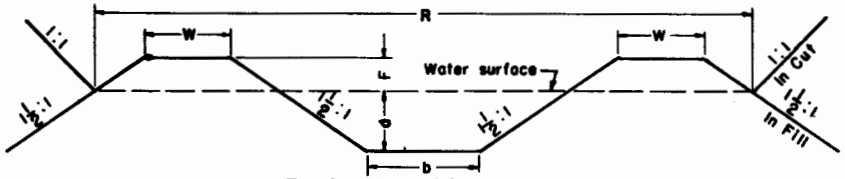
8. "Flow of Water in Drainage Channels", by C. E. Ramser, USDA Technical Bulletin No. 129, 1929.
9. "Some Better Kutter's Formula Coefficients", by R. E. Horton, Engineering News, February 24, May 4, 1916.

Figure 16.3-2

IRRIGATION DITCH SECTIONS WITH REQUIRED LATERAL BEDS



LATERAL BED BEFORE DITCH IS PULLED



FINISHED DITCH SECTION

								s = 0.0005				s = 0.001				s = 0.002				s = 0.003			
								n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04		n = 0.03		n = 0.04	
Ditch No.	b	d	F	W	R	A	r	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q	V	Q
	feet	feet	feet	feet	feet	sq.ft.	feet	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs	ft/sec.	cfs
612	0.5	1.0	0.5	1.00	8.5	2.00	0.49	0.69	1.4	0.51	1.0	0.97	1.9	0.73	1.5	1.37	2.7	1.03	2.1	1.68	3.4	1.26	2.5
1212	1.0	1.0	0.5	1.50	10.0	2.50	0.54	0.73	1.8	0.55	1.4	1.03	2.6	0.78	2.0	1.47	3.7	1.10	2.8	1.79	4.5	1.35	3.4
1812	1.5	1.0	0.5	2.00	11.5	3.00	0.59	0.78	2.3	0.58	1.7	1.10	3.3	0.83	2.5	1.56	4.7	1.17	3.5	1.91	5.7	1.43	4.3
2412	2.0	1.0	0.5	2.50	13.0	3.50	0.62	0.81	2.8	0.60	2.1	1.13	4.0	0.86	3.0	1.61	5.6	1.21	4.2	1.97	6.9	1.48	5.2
1214	1.0	1.2	0.7	1.25	11.3	3.36	0.63	0.81	2.7	0.61	2.0	1.15	3.9	0.87	2.9	1.63	5.5	1.22	4.1	1.99	6.7	1.50	5.0
1814	1.5	1.2	0.7	1.50	12.3	3.96	0.68	0.86	3.4	0.64	2.5	1.21	4.8	0.91	3.6	1.71	6.8	1.28	5.1	2.09	8.3	1.57	6.2
2414	2.0	1.2	0.7	2.00	13.8	4.56	0.72	0.89	4.1	0.67	3.1	1.25	5.7	0.94	4.3	1.78	8.1	1.33	6.1	2.18	9.9	1.63	7.4
1816	1.5	1.33	0.77	1.75	13.6	4.65	0.74	0.90	4.2	0.68	3.2	1.28	6.0	0.96	4.5	1.81	8.4	1.36	6.3	2.22	10.3	1.66	7.7
2416	2.0	1.33	0.77	2.00	14.6	5.31	0.78	0.94	4.9	0.71	3.8	1.33	7.1	0.99	5.3	1.88	10.0	1.41	7.5	2.30	12.3	1.72	9.2
2418	2.0	1.5	1.0	1.50	15.5	6.38	0.86	1.00	6.4	0.75	4.8	1.42	9.1	1.06	6.8	2.00	12.8	1.50	9.6	2.15	15.6	1.83	11.7
3618	3.0	1.5	1.0	2.00	17.5	7.88	0.94	1.06	8.4	0.80	6.3	1.50	11.8	1.12	8.8	2.13	16.8	1.59	12.5	2.60	20.5	1.95	15.4
2421	2.0	1.75	1.1	1.75	17.4	8.10	0.98	1.09	8.8	0.82	6.6	1.55	12.6	1.15	9.3	2.19	17.7	1.64	13.3	2.67	21.6	2.00	16.2
3621	3.0	1.75	1.1	2.50	19.9	9.85	1.06	1.15	11.3	0.86	8.5	1.63	16.1	1.22	12.0	2.30	22.7	1.73	17.0	2.82	27.8	2.11	20.8
4821	4.0	1.75	1.1	3.00	21.9	11.60	1.13	1.20	13.9	0.90	10.4	1.70	19.7	1.27	14.7	2.40	27.8	1.80	20.9	2.94	34.1	2.21	25.6
3624	3.0	2.0	1.3	2.25	21.3	12.00	1.18	1.24	14.9	0.93	11.2	1.75	21.0	1.31	15.7	2.47	29.6	1.86	22.3	3.03	36.4	2.27	27.2
4824	4.0	2.0	1.3	3.00	23.8	14.00	1.25	1.28	17.9	0.96	13.4	1.82	25.5	1.36	19.0	2.57	36.0	1.93	27.0	3.15	44.1	2.36	33.0

A = cross sectional area in square feet.
r = hydraulic radius in feet.
n = coefficient of roughness.
Use n = 0.03 for bare ground.
Use n = 0.04 for grassed ditch bottom.

s = slope in feet per foot.
V = velocity in feet per second.
Q = capacity of ditch in cubic feet per second.

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SOIL CONSERVATION SERVICE

Figure 16.4-1

5,L-12,917

16-7

DISCHARGE CAPACITY OF CANALS
Based on Manning's Formula

n = .035
Side slopes 1½:1
Bottom width 4 feet

d = ft. a = sq. ft. v = ft/sec. Q = cu. ft/sec.

Depth of Water	Area (a)	Slope in Feet per 100 Feet											
		.10		.15		.20		.30		.40		.50	
		v	Q	v	Q	v	Q	v	Q	v	Q	v	Q
.8	4.16							1.65	6.86	1.91	7.94	2.14	8.90
1.0	5.50					1.52	8.36	1.86	10.23	2.15	11.82	2.41	13.25
1.2	6.96			1.46	10.16	1.69	11.76	2.06	14.34	2.39	16.63		
1.4	8.54			1.57	13.41	1.82	15.54	2.23	19.04	2.59	22.12		
1.6	10.24	1.38	14.13	1.69	17.31	1.96	20.07	2.40	24.58				
1.8	12.06	1.47	17.73	1.80	21.71	2.08	25.08	2.55	30.75				
2.0	14.00	1.56	21.84	1.91	26.74	2.20	30.80						

Figure 16.4-2

DISCHARGE CAPACITY OF CANALS
Based on Manning's Formula

n = .035
Side slopes 1½:1
Bottom width 6 feet

d = ft. a = sq. ft. v = ft/sec. Q = cu. ft/sec.

Depth of Water	Area (a)	Slope in Feet per 100 Feet											
		.10		.15		.20		.30		.40		.50	
		v	Q	v	Q	v	Q	v	Q	v	Q	v	Q
.8	5.76							1.74	10.02	2.01	11.58	2.25	12.96
1.0	7.50					1.61	12.07	1.96	14.70	2.27	17.02	2.54	19.05
1.2	9.36			1.54	14.41	1.78	16.66	2.18	20.40	2.52	23.59		
1.4	11.34			1.67	18.94	1.94	22.00	2.37	26.88				
1.6	13.44	1.47	19.76	1.79	24.06	2.07	27.82	2.43	34.14				
1.8	15.66	1.56	24.43	1.91	29.91	2.20	34.45						
2.0	18.00	1.65	29.70	2.02	36.36	2.33	41.94						
2.2	20.46	1.74	35.60	2.13	43.58								
2.4	23.04	1.82	41.93	2.22	51.15								
2.6	25.74	1.89	48.65										
2.8	28.56	1.97	56.26										

Figure 16.4-3

DISCHARGE CAPACITY OF CANALS
Based on Manning's Formula

n = .035

Side slopes 1½:1
Bottom width 8 feet

d = ft. a = sq. ft. v = ft/sec. Q = cu. ft/sec.

Depth of Water	Area (a)	Slope in Feet per 100 Feet											
		.10		.15		.20		.30		.40		.50	
		v	Q	v	Q	v	Q	v	Q	v	Q	v	Q
1.0	9.50					1.67	15.86	2.03	19.29	2.35	22.32		
1.2	11.76			1.58	18.58	1.83	21.52	2.25	26.46				
1.4	14.14	1.41	19.94	1.73	24.46	2.00	28.28	2.45	34.64				
1.6	16.64	1.53	25.46	1.87	31.12	2.15	35.78						
1.8	19.26	1.62	31.20	1.99	38.33	2.30	44.30						
2.0	22.00	1.72	37.84	2.11	46.42								
2.2	24.86	1.81	45.00	2.21	54.94								
2.4	27.84	1.89	52.62	2.31	64.31								
2.6	30.94	1.97	60.95										
2.8	34.16	2.05	70.03										

Figure 16.4-4

DISCHARGE CAPACITY OF CANALS
Based on Manning's Formula

n = .035

Side slopes 1½:1
Bottom width 10 feet

d = ft. a = sq. ft. v = ft/sec. Q = cu. ft/sec.

Depth of Water	Area (a)	Slope in Feet per 100 Feet									
		.05		.10		.15		.20		.30	
		v	Q	v	Q	v	Q	v	Q	v	Q
1.4	16.94			1.44	24.39	1.78	30.15	2.06	34.90	2.52	42.69
1.6	19.84			1.52	31.15	1.92	38.09	2.21	43.85		
1.8	22.86	1.18	26.97	1.67	38.18	2.05	46.86	2.37	54.18		
2.0	26.00	1.24	32.24	1.77	46.02	2.16	56.16				
2.2	29.26	1.31	38.33	1.86	54.42	2.28	66.71				
2.4	32.64	1.37	44.72	1.93	63.00	2.38	77.68				
2.6	36.14	1.43	51.68	2.04	73.73						
2.8	39.76	1.48	58.84	2.11	83.89						
3.0	43.50	1.56	67.86								
3.2	47.36	1.61	76.25								

Figure 16.4-5

2. OPEN CHANNEL FLOW (CONT'D)

Open Channel Formulas (cont'd)

Example of Open Channel Flow Determination (cont'd)

$$(OX)^2 = 1^2 + 2^2$$
$$= 1 + 4 = 5'$$
$$OX = (5)^{\frac{1}{2}} \text{ or the square root of } 5'$$

From any table of square roots of numbers:

$$OX = 2.236' = YZ$$

Then: OX + Bottom width + YZ = Wetted Perimeter, p
$2.236' + 6' + 2.236' = 10.47'$

The hydraulic radius is: $\frac{a}{p} = \frac{8}{10.47'} = 0.76 = r$

With this information the solution of Manning's Formula is carried out:

$$v = \frac{1.486}{n} r^{2/3} s^{1/2}$$

$$= \frac{1.486}{.030} \times 0.76^{2/3} \times .003^{1/2}$$

By division and from any tables of powers or roots of numbers (King's Handbook of Hydraulics)

$$V = 49.53 \times .932 \times .05477 = 2.26 \text{ f.p.s.}$$

$$Q = av = 8 \times 2.26 = 18.1 \text{ c.f.s.}$$

Solution by use of Graph Figure 16.1:

By use of tables or by mathematical means determine the cross sectional area and the hydraulic radius of the channel under consideration. Select the proper coefficient of roughness, "n" from Figure 16.3-1 and 2.

Enter Figure 16.1 on the left side and locate the required hydraulic radius value. Locate the required coefficient of roughness value on the vertical scale immediately to the right. With a straight edge placed on these two points, extend a line to the vertical pivot line in the center of the graph. Connect this latter point to the desired slope value on the vertical scale on the right side of the graph with the straight edge. Read the velocity, v on the vertical scale immediately to the right of the pivot line at the point where the straight edge crosses. With this value of velocity, apply the fundamental equation of hydraulic flow Q = av to determine the quantity of flow.

If it is desired to determine the design of a channel from a known quantity of flow, n factor and slope, the proper hydraulic radius may be

2. OPEN CHANNEL FLOW (CONT'D)

Open Channel Formulas (cont'd)

Example of Open Channel Flow Determination (cont'd)

determined by working backward from the above procedure. This holds true also if quantity, n factor, velocity and hydraulic radius are known and it is desired to determine the slope of a channel.

Limitations

In dealing with problems of open channel flow, there are limitations which must be taken into consideration. It is recognized that one of the first items to be considered in soil conservation work is that of erosion resulting from such flow. It is further easily recognized that erosion by such means is a direct result of the relationship between the velocity of the flow of water and the material of the channel in which the flow occurs.

The ideal open channel design in natural materials will carry the maximum quantity of flow at a velocity where channel erosion is a minimum, but will have sufficient velocity to avoid deposition of silt which may be in suspension in the water or to discourage growth of aquatic plants such as moss. Figure 16.5 is a listing of permissible velocities of open channel flow for various natural materials.

Critical Flow

Critical flow is a term used to describe open channel flow when certain relationships exist between energy head, discharge and depth of flow. Critical flow exists when the discharge is the greatest for a given energy head measured from the bottom of the channel or conversely, the energy head is a minimum for a given discharge. The technical coverage of these facts are beyond the scope of this handbook. For such information, reference is made to Section 5, "Hydraulics" of the National Engineering Handbook.

As flow approaches critical velocity, it is very turbulent and unstable. If velocities are planned to be near critical velocity in ditch or canal sections, an additional free board should be provided to give protection against overtopping from excessive wave action.

In most open channel spillway conditions confronting the field technician it is essential that he know what will control the amount of discharge through the spillway under given physical conditions. In other words, determination must be made if the spillway layout is such that critical flow or open channel subcritical flow will govern the maximum amount of discharge under a given water surface elevation in the pool area at the entrance of the spillway.

Flow in Open Channel Spillways

The flow of water through open channel spillways is an important problem often confronting service personnel. In general, when dealing

SAFE VELOCITIES - Open Channel Flow
in Erodible Material

Nonvegetated Channels	
Noncolloidal sandy or silty loam	1.5 - 3.0 f.p.s.
Ordinary loam	2.5 - 3.5 f.p.s.
Colloidal Clay	3.0 - 5.0 f.p.s.
Fine gravel	2.5 - 5.0 f.p.s.
Coarse gravel	4.0 - 6.0 f.p.s.
Cobbles, shales, and hardpans	5.0 - 6.5 f.p.s.
Vegetated Channels	
(Refer to Fig. 5.13, Pg. 5.23, Engineering Handbook for Work Unit Staffs.)	

Figure 16.5

2. OPEN CHANNEL FLOW (CONT'D)

Flow in Open Channel Spillways (cont'd)

with such a spillway either one of two hydraulic conditions will govern discharge.

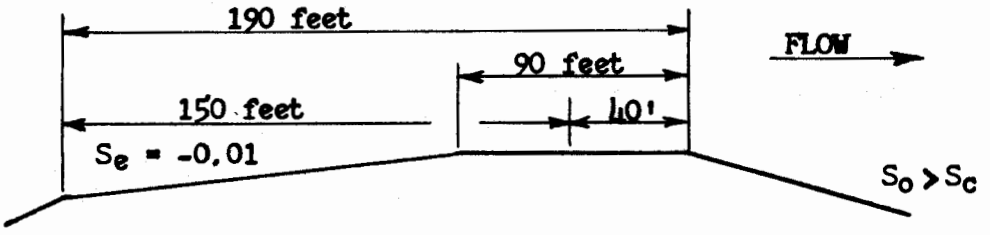
If the spillway is constructed such that its operation throughout the length of its course causes uniform flow conditions, the solution of discharge is obtained by application of open channel determinations given in the preceding part of this section. If, on the other hand, the spillway is so constructed that non-uniform flow conditions will exist, the hydraulics of discharge become considerably more involved. Such a condition would be obvious if the gradient of the spillway course were to be suddenly steepened. The existance of this condition in spillways is generally unavoidable, therefore a basic understanding of critical flow is essential if discharge problems are to be solved.

Figures 16.6-1 to 16.6-6 inclusive are head-discharge curves for use in designing grassed emergency spillway for dams. Figures 16.6-1 and 16.6-2 are head-discharge curves for sub-critical spillway outlet with slopes of 0.5 and 1.0 percent. Figures 16.6-3 to 16.6-6 inclusive are for spillways with outlet slopes equal to or greater than critical slope.

Critical slope is a function of discharge. When the unit discharge is increased the critical slope value is decreased. In using these curves, the permissable error will not be exceeded if the super-critical flow curves are used for spillway outlet slopes of 1.3 percent or greater. Therefore, use Figures 16.6-3 through 16.6-6 for spillway outlet slopes of 1.3 percent or greater; Figure 16.6-2 for outlet slopes of 0.8 percent to 1.3 percent; and, Figure 16.6-1 for outlet slopes from 0.5 percent to 0.8 percent.

Figure 16.7-1 gives depth-discharge relationships for various slopes of the outlet channel of the emergency spillway. Figure 16.7-2 gives velocity-discharge relationships at the control section of the emergency spillway. In using these curves it is first necessary to determine the permissable velocity at the control section. This can be computed from information supplied in SCS Technical Publication 61, "Handbook of Channel Design for Soil and Water Conservation", or from some other source. The following example describes the application of the curves:

Problem: It is desired to design an emergency spillway with 2:1 side-slopes to carry a peak flow of 223 c.f.s. It was noted from site topography that the spillway will have an inlet slope of -0.01, a total length of 190 feet, a 90 foot level crest length, and an outlet slope greater than critical. (See sketch)



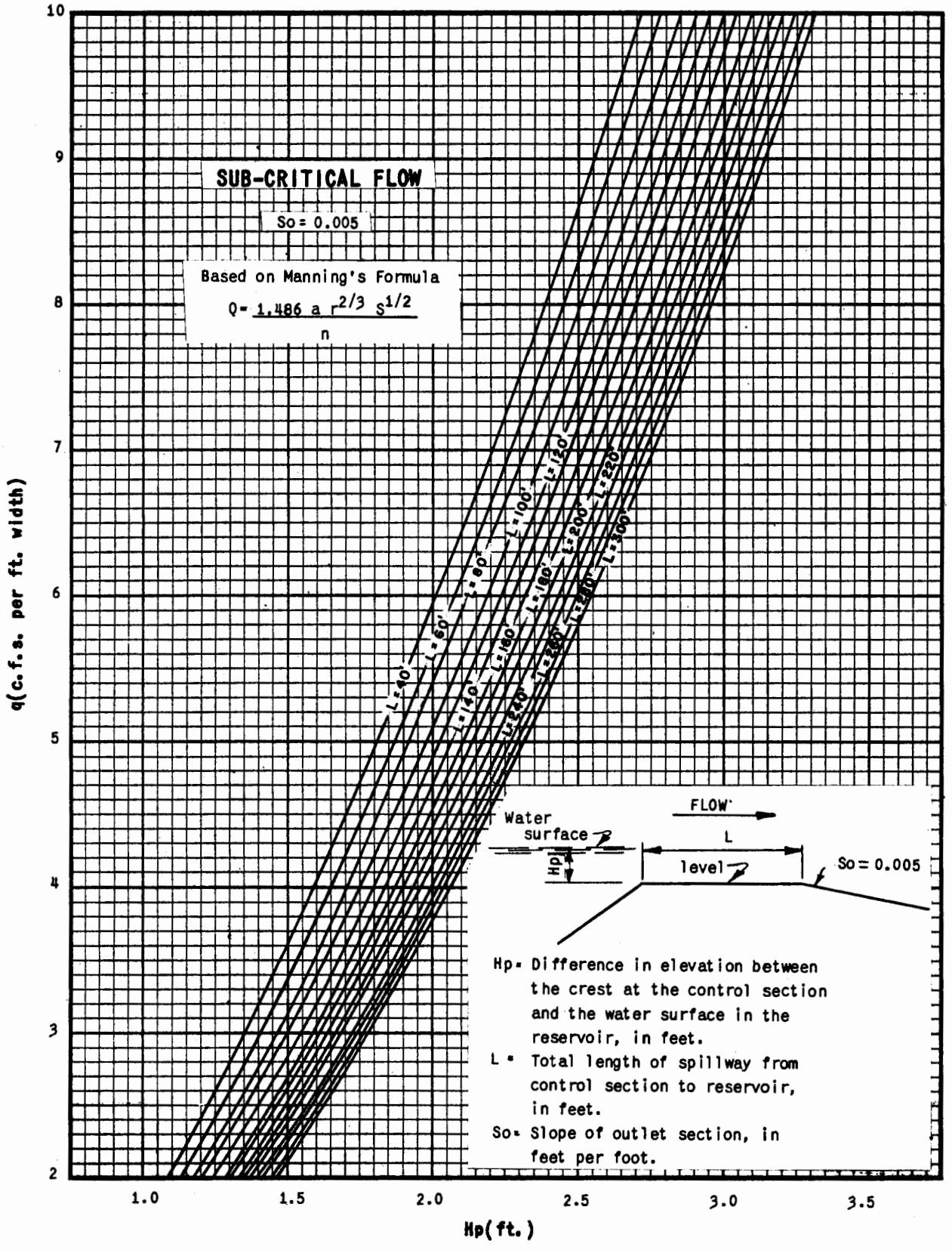


Figure 16.6-1 - HEAD DISCHARGE CURVES FOR 1 FT. WIDTH OF EMERGENCY SPILLWAY

(Based on Manning's "n" of 0.040)

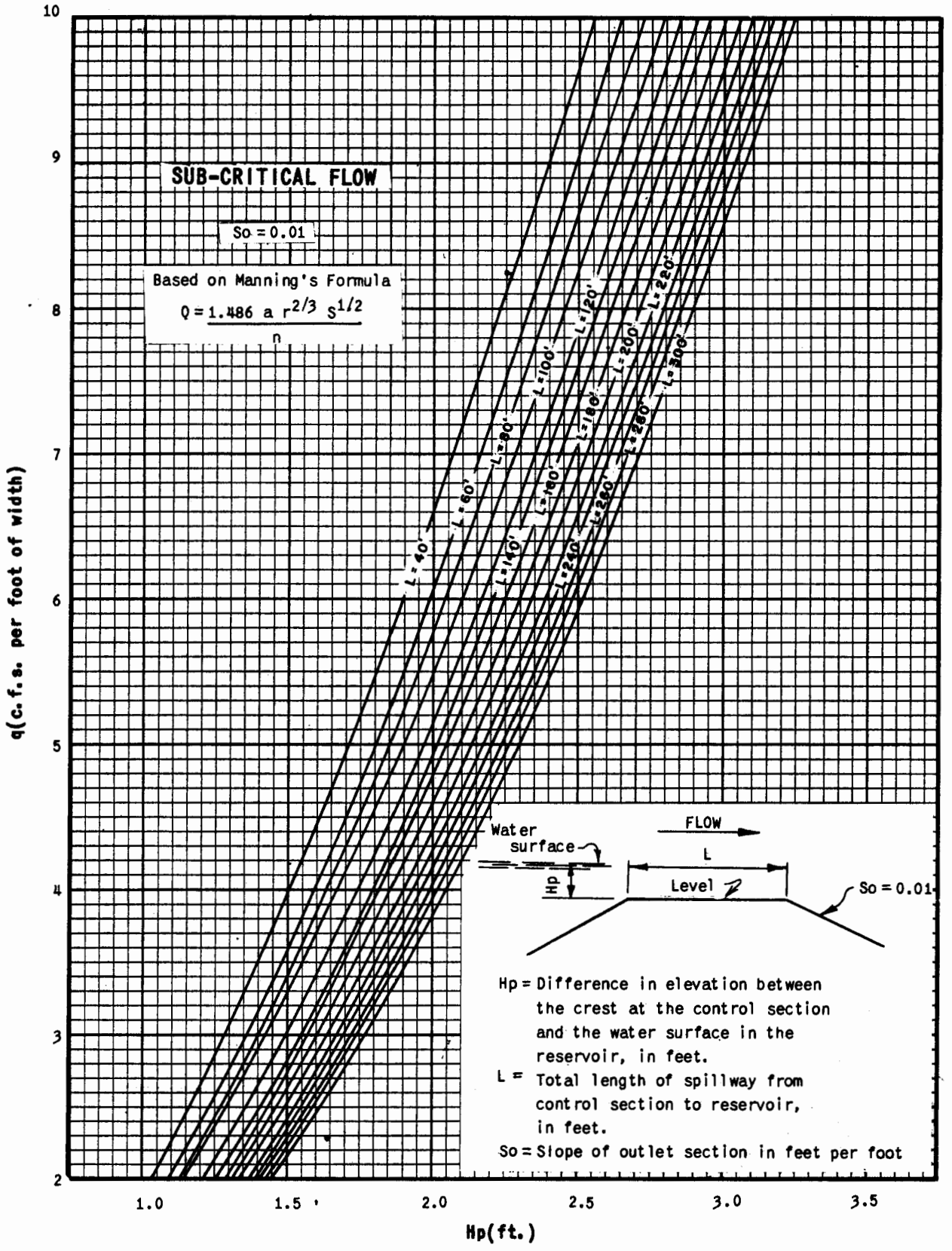


Figure 16.6-2 - HEAD DISCHARGE CURVES FOR 1 FT. WIDTH OF EMERGENCY SPILLWAY

(Based on Manning's "n" of 0.040)

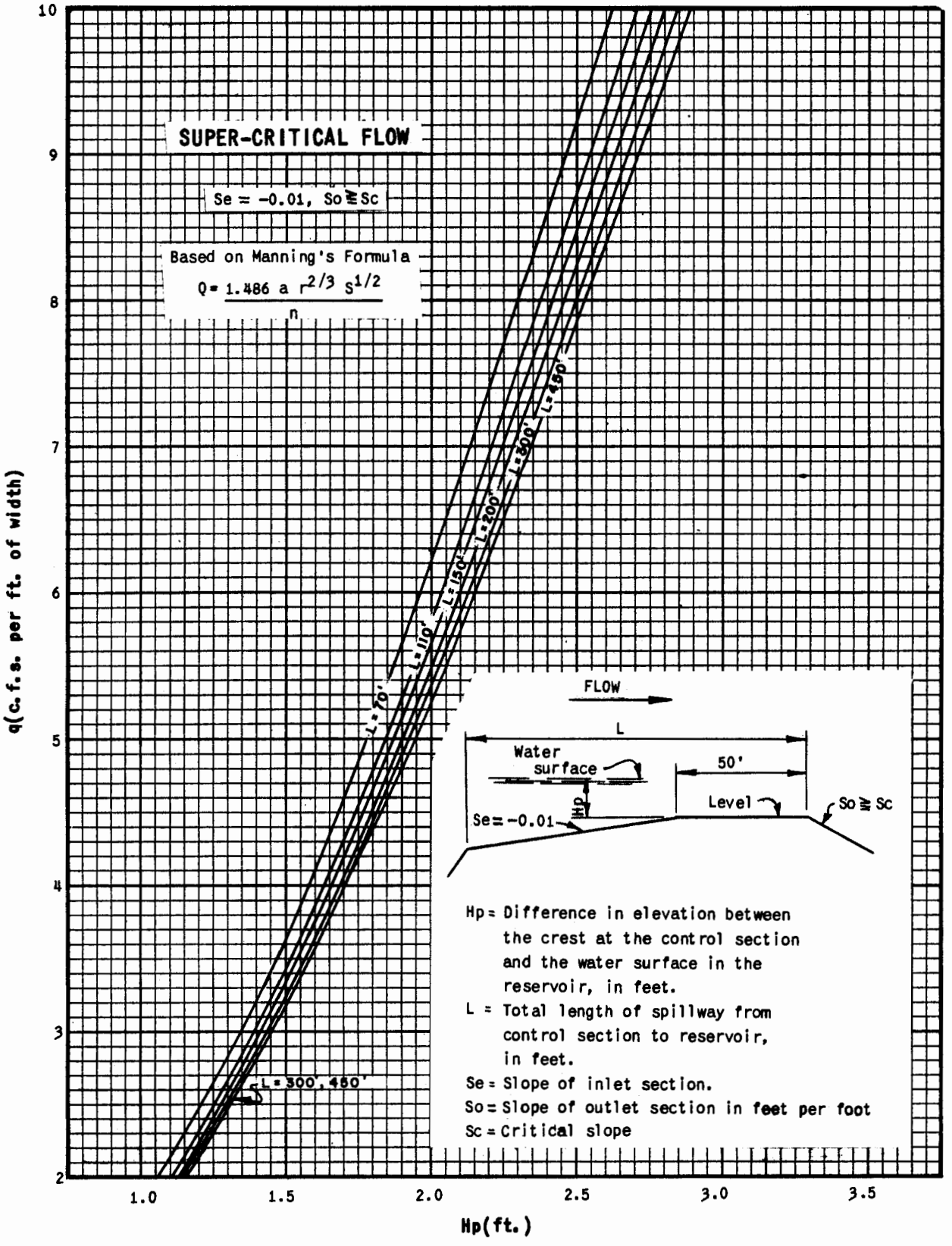


Figure 16.6-3 - HEAD DISCHARGE CURVES FOR 1 FT. WIDTH OF EMERGENCY SPILLWAY

(Based on Manning's "n" of 0.040)

5,L-16,437-3(7)

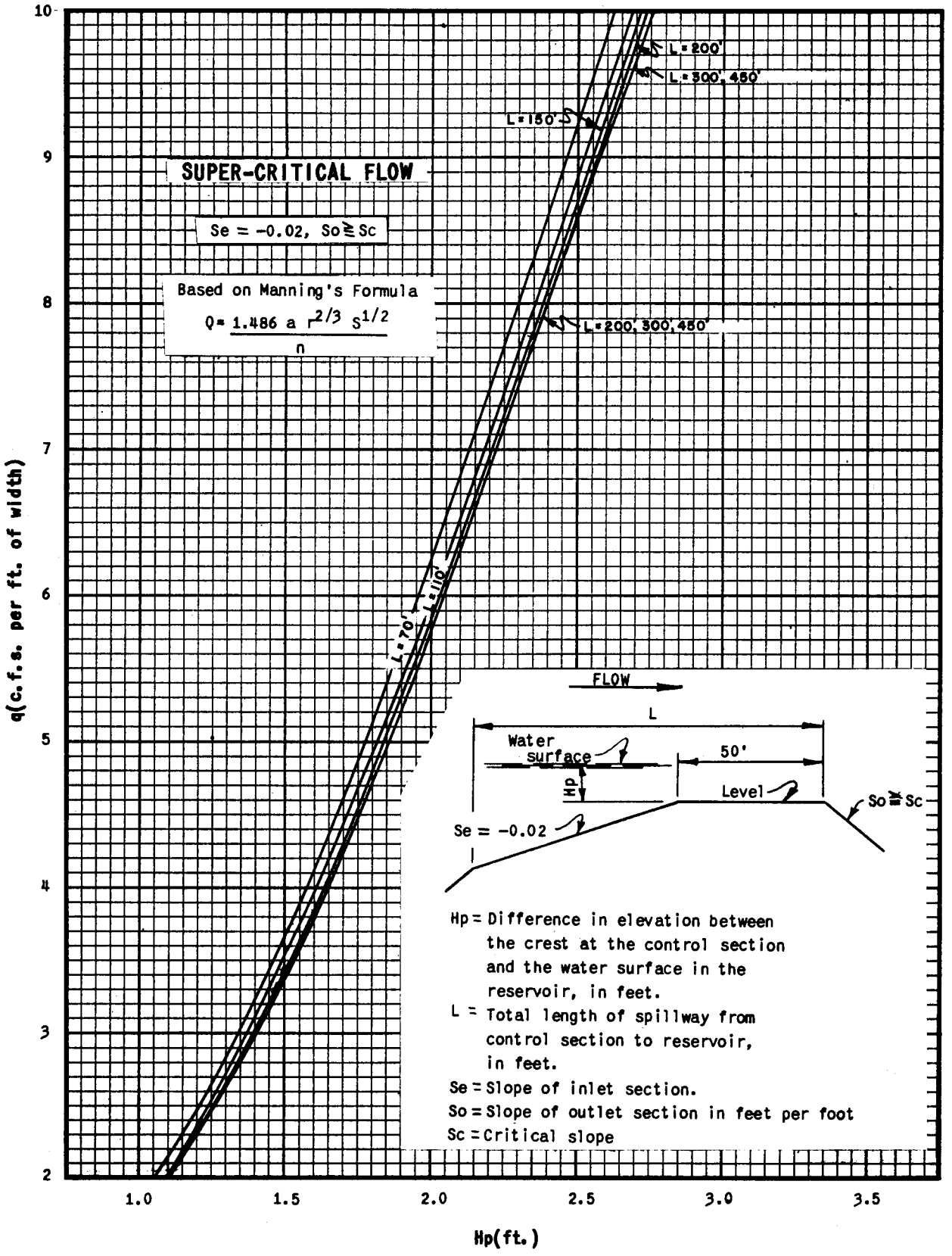


Figure 16.6-4 - HEAD DISCHARGE CURVES FOR 1 FT. WIDTH OF EMERGENCY SPILLWAY

(Based on Manning's "n" of 0.040)

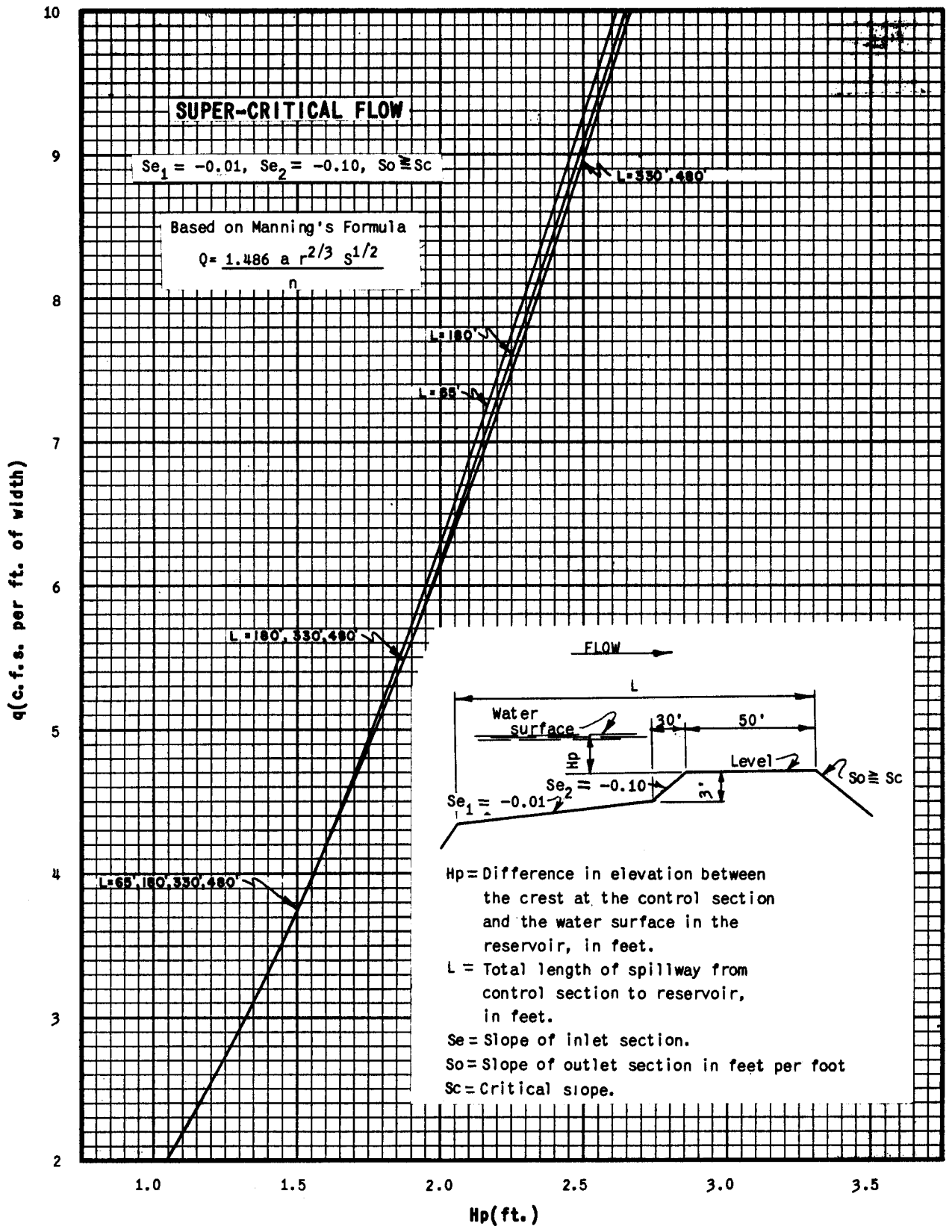


Figure 16.6-5 - HEAD DISCHARGE CURVES FOR 1 FT. WIDTH OF EMERGENCY SPILLWAY

(Based on Manning's "n" of 0.040)

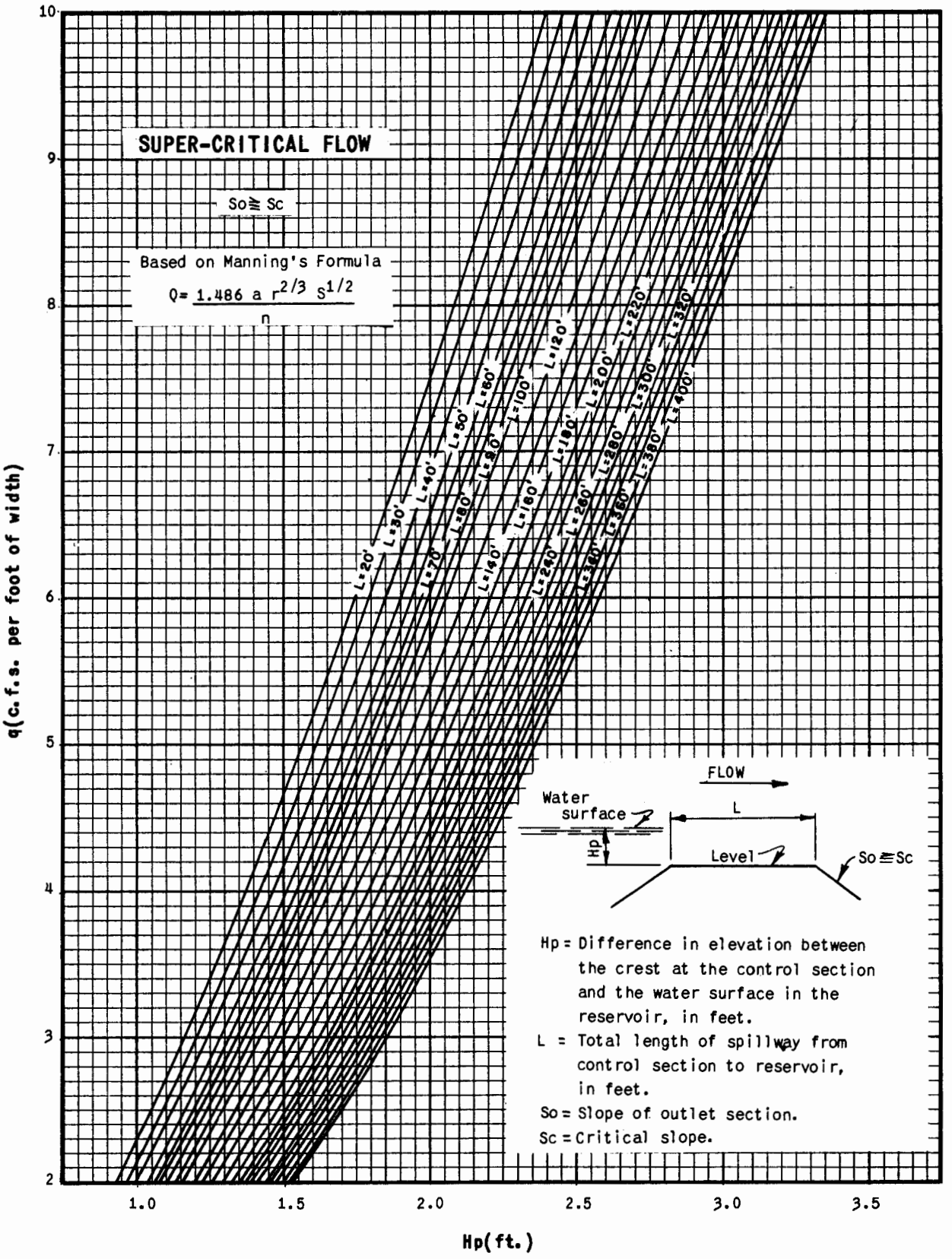


Figure 16.6-6 - HEAD DISCHARGE CURVES FOR 1 FT. WIDTH OF EMERGENCY SPILLWAY

(Based on Manning's "n" of 0.040)

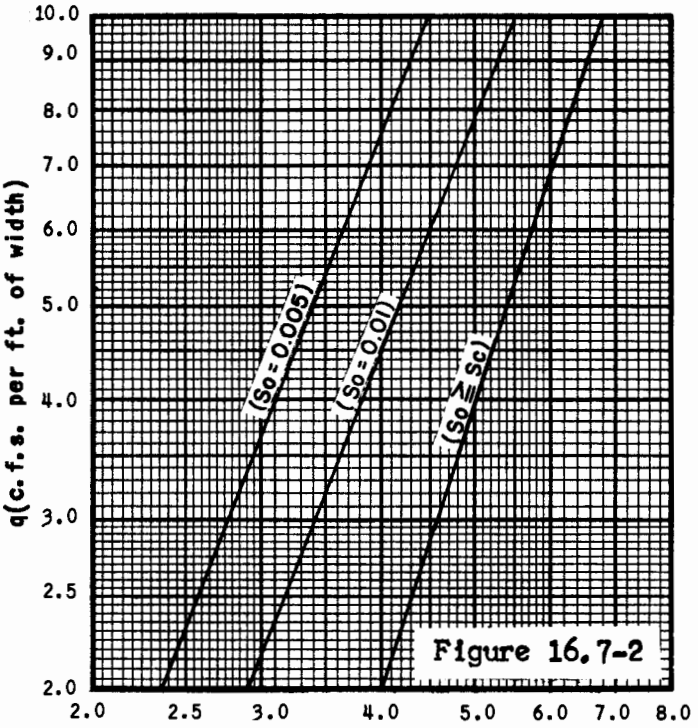


Figure 16.7-2

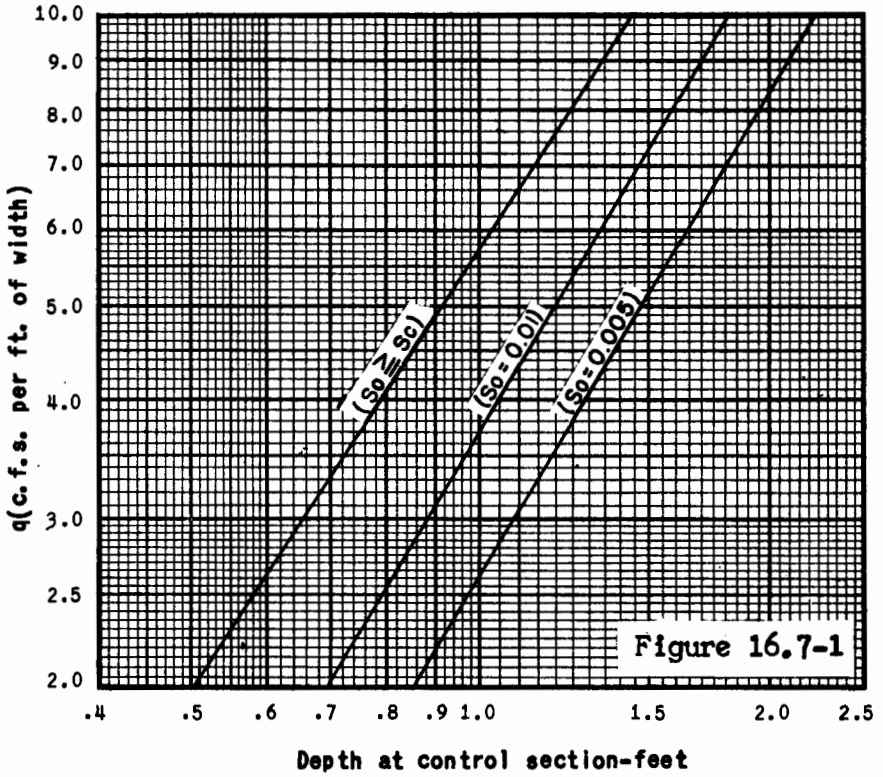


Figure 16.7-1

CHARTS OF VELOCITIES AND DEPTHS AT THE CONTROL SECTION AGAINST DISCHARGE PER FOOT OF WIDTH

2. OPEN CHANNEL FLOW (CONT'D)

Flow in Open Channel Spillways (cont'd)

The permissible velocity was found to be 5.2 f.p.s.

Solution: Entering Figure 16.7-2 with a velocity of 5.2 f.p.s., and using the appropriate curve, ($S_o \geq S_c$), the discharge, (q), per foot of width is found to be 4.4 c.f.s. The necessary head, (H_p), to produce this discharge, (q), can be determined as follows:

Step 1. Since the given level crest length is 90 feet and the level crest length on Figure 16.6-3 is 50 feet, subtract 40 feet, (90-50), from the given length to obtain an adjusted length. The adjusted length then equals 190 feet minus 40 feet = 150 feet.

Step 2. Enter Figure 16.6-3 with a length of 150 feet and q = 4.4 c.f.s., and find H_p = 1.74 feet.

Step 3. From Figure 16.6-6, with q = 4.4 c.f.s., obtain following:

For a crest length of 50 feet, H_p = 1.59 feet

For a crest length of 90 feet, H_p = 1.72 feet

The difference in H_p for an increase in crest length of 40 feet =

1.72 feet - 1.59 feet = 0.13

Step 4. Add the value of H_p from Step 2 to the difference in H_p found in Step 3 to obtain the total H_p.

H_p = 1.74 feet + 0.13 feet = 1.87 feet

It is evident that, in case the length of the level crest section is equal to that shown on the curve, H_p could be read directly with no correction necessary.

In order to find the required bottom width of the spillway, the depth at the control section is needed. Entering Figure 16.7-1 with q = 4.4 c.f.s., and using the appropriate curve, ($S_o \geq S_c$), the depth at the control section is found to be 0.84 feet.

The two following equations will be employed to complete the solution.

$$Q = wq \qquad (1)$$

$$w = b + zd \qquad (2)$$

where Q = total discharge in c.f.s.

w = width of the equivalent section in feet

q = discharge per foot of width in c.f.s.

2. OPEN CHANNEL FLOW (CONT'D)

Flow in Open Channel Spillways (cont'd)

b = bottom width of the trapezoidal section

z = side slope ratio (horizontal divided by vertical)

d = depth at the control section (d_c or d_n)

By equation (1):

$$Q = wq$$

$$\therefore w = Q/q$$

$$w = 223/4.4 = 50.68 \text{ feet}$$

By equation (2)

$$w = b + zd$$

$$\therefore b = w - zd$$

$$b = 50.68 - (2 \times 0.84) = 49.0 \text{ feet}$$

The bottom width of the spillway in question is thus found to be 49 feet. This would be the minimum bottom width for the design peak flow and the specified permissible velocity. Freeboard for wave action and frost action shall be provided above the determined H_p value of 1.87 feet.

3. WEIR FLOW

Definition

A weir is a notch of regular shape through which water flows. Weirs of various dimensions and shapes are used in hydraulic structures to function as spillways and water measuring devices. In soil conservation work the rectangular weir is widely used. The basic formula for a rectangular weir is:

$$Q = CLH^{3/2}$$

Q = rate of discharge in cubic feet per second (c.f.s.)
C = coefficient dependent on the shape of the weir.
L = width of weir in feet.
H = head which is the distance in feet from the crest to the water surface taken far enough upstream to obviate effect of surface contraction.

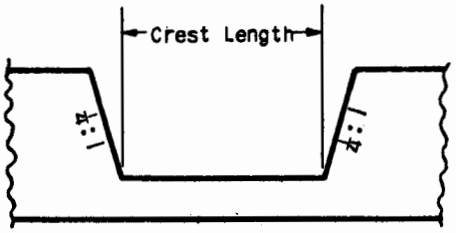
3. WEIR FLOW (CONT'D)

Use and Limitations

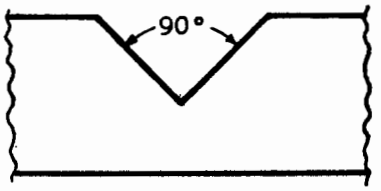
This formula does not take velocity of approach or end contractions into consideration. The reader is referred to texts on hydraulics for a full understanding of these factors. Ordinarily the basic formula will give results that are in keeping with the accuracy of the estimates that must be made in most weir computations.

The weir coefficient will vary for each particular crest and is dependent on the head, entrance conditions, shape of crest, and degree of submergence, if any. Of all these variables, the shape of crest is the most important factor affecting the value of (C), providing there is no submergence. Weirs are used primarily as measuring devices and have infrequent application in structural design. The flow through spillways, drops, and most gully control structures is computed by broad-crested weir formulae.

Cippoletti and Triangular Notch Weirs. These type weirs are commonly used for measurement purposes. The triangular notch weir is suitable for measuring small quantities of water while the cippoletti weir is suitable for measuring water over a wide range of conditions.



Cippoletti Weir
Figure 16.8



v - Notch or Triangular Weir
Figure 16.9

Figures 16.11-1, 2 & 3 give the discharge of cippoletti weirs for a range of lengths (L) and heads (H). Figure 16.12 gives the discharge of 90° triangular weirs.

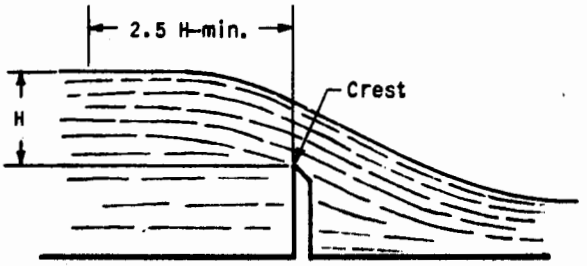


Figure 16.10

Figure 16.10 shows a cross-section of a typical weir crest.

These weirs must be installed in such a manner that there will be little, if any, velocity of approach. The cross-sectional area of the

Discharge table for Cipolletti weirs with complete contractions

Head, H[1]		Discharge, Q, for crest length, L, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0.10	1 3/16	0.11	0.16	0.23	0.33	0.44	0.64	0.85	1.06
.11	1 5/16	.12	.18	.26	.38	.50	.74	.98	1.23
.12	1 7/16	.14	.21	.29	.43	.57	.84	1.12	1.40
.13	1 9/16	.16	.24	.33	.48	.64	.95	1.26	1.58
.14	1 11/16	.17	.26	.36	.54	.71	1.06	1.41	1.73
.15	1 13/16	.19	.29	.39	.59	.79	1.17	1.56	1.96
.16	1 15/16	.21	.32	.43	.65	.87	1.29	1.72	2.15
.17	2 1/16	.23	.36	.47	.71	.96	1.41	1.89	2.36
.18	2 3/16	.25	.39	.51	.77	1.04	1.54	2.06	2.57
.19	2 1/4	.28	.42	.56	.83	1.12	1.67	2.23	2.79
.20	2 3/8	.30	.45	.60	.90	1.20	1.81	2.41	3.01
.21	2 1/2	.32	.48	.64	.97	1.29	1.94	2.59	3.24
.22	2 5/8	.35	.52	.69	1.04	1.38	2.08	2.78	3.47
.23	2 3/4	.37	.55	.74	1.11	1.47	2.23	2.97	3.71
.24	2 7/8	.39	.59	.79	1.18	1.57	2.38	3.17	3.96
.25	3	.42	.63	.84	1.25	1.67	2.53	3.37	4.21
.26	3 1/8	.45	.67	.89	1.33	1.77	2.68	3.57	4.46
.27	3 1/4	.47	.70	.94	1.40	1.87	2.83	3.78	4.72
.28	3 3/8	.50	.74	.99	1.48	1.97	2.99	3.99	4.99
.29	3 1/2	.53	.79	1.04	1.56	2.08	3.15	4.21	5.26
.30	3 5/8	.56	.83	1.10	1.64	2.19	3.32	4.43	5.53
.31	3 3/4	.59	.87	1.15	1.73	2.30	3.49	4.65	5.81
.32	3 13/16	.61	.91	1.21	1.80	2.41	3.66	4.88	6.09
.33	3 15/16	.64	.95	1.27	1.89	2.52	3.83	5.11	6.38
.34	4 1/16	.67	1.00	1.32	1.98	2.64	4.00	5.34	6.67
.35	4 3/16	.70	1.04	1.38	2.07	2.75	4.18	5.58	6.97
.36	4 5/16	.73	1.09	1.44	2.16	2.87	4.36	5.82	7.27
.37	4 7/16	.77	1.13	1.50	2.25	2.99	4.55	6.06	7.58
.38	4 9/16	.80	1.18	1.57	2.34	3.11	4.73	6.31	7.89
.39	4 11/16	.83	1.23	1.63	2.43	3.24	4.92	6.56	8.20
.40	4 13/16	.87	1.28	1.69	2.53	3.36	5.11	6.81	8.52
.41	4 15/16	.90	1.32	1.76	2.62	3.49	5.30	7.07	8.84
.42	5 1/16	.93	1.37	1.82	2.72	3.61	5.50	7.33	9.16
.43	5 3/16	.97	1.42	1.89	2.81	3.74	5.70	7.59	9.49
.44	5 1/4	1.00	1.47	1.95	2.91	3.87	5.90	7.86	9.83
.45	5 3/8	1.04	1.53	2.02	3.01	4.01	6.10	8.13	10.2
.46	5 1/2	1.07	1.58	2.09	3.11	4.14	6.30	8.40	10.5
.47	5 5/8	1.11	1.63	2.16	3.21	4.28	6.51	8.68	10.8
.48	5 3/4	1.15	1.68	2.23	3.32	4.41	6.72	8.96	11.2
.49	5 7/8	1.18	1.74	2.30	3.42	4.55	6.93	9.24	11.5
.50	6	1.22	1.79	2.37	3.53	4.69	7.14	9.52	11.9
.51	6 1/8	1.26	1.85	2.44	3.64	4.83	7.36	9.81	12.3
.52	6 1/4	1.30	1.90	2.51	3.74	4.97	7.57	10.1	12.6
.53	6 3/8	1.34	1.96	2.59	3.85	5.12	7.79	10.4	13.0
.54	6 1/2	1.38	2.02	2.66	3.96	5.26	8.02	10.7	13.4
.55	6 5/8	1.42	2.07	2.74	4.07	5.41	8.24	11.0	13.7
.56	6 3/4	1.46	2.13	2.81	4.18	5.56	8.47	11.3	14.1
.57	6 13/16	1.50	2.19	2.89	4.30	5.71	8.69	11.6	14.5
.58	6 15/16	1.54	2.25	2.97	4.41	5.86	8.92	11.9	14.9
.59	7 1/16	1.58	2.31	3.05	4.53	6.01	9.15	12.2	15.3
.60	7 3/16	1.62	2.37	3.13	4.64	6.17	9.39	12.5	15.6
.61	7 5/16	1.67	2.43	3.20	4.76	6.32	9.62	12.8	16.0
.62	7 7/16	1.71	2.49	3.28	4.88	6.47	9.86	13.1	16.4
.63	7 9/16	1.75	2.55	3.37	5.00	6.63	10.1	13.5	16.8
.64	7 11/16	1.80	2.62	3.45	5.12	6.79	10.3	13.8	17.2

See footnote at end of table.

Figure 16.11-1

Discharge table for Cipolletti weirs with complete contractions—Continued

Head, H[1]		Discharge, Q, for crest length, L, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0.65	7 13/16	1.84	2.68	3.53	5.24	6.95	10.6	14.1	17.6
.66	7 15/16	1.89	2.75	3.61	5.36	7.11	10.8	14.4	18.1
.67	8 1/16	1.93	2.81	3.70	5.48	7.28	11.1	14.8	18.5
.68	8 1/16	1.98	2.87	3.79	5.61	7.44	11.3	15.1	18.9
.69	8 1/4	2.02	2.94	3.87	5.73	7.61	11.6	15.4	19.3
.70	8 3/8	2.07	3.01	3.95	5.86	7.77	11.8	15.8	19.7
.71	8 1/2	2.12	3.07	4.04	5.99	7.94	12.1	16.1	20.1
.72	8 5/8	2.16	3.14	4.13	6.12	8.11	12.3	16.5	20.6
.73	8 3/4	2.21	3.21	4.22	6.24	8.28	12.6	16.8	21.0
.74	8 7/8	2.26	3.28	4.31	6.38	8.45	12.9	17.1	21.4
.75	9	2.31	3.35	4.40	6.51	8.62	13.1	17.5	21.9
.76	9 1/8	2.36	3.42	4.49	6.64	8.80	13.4	17.8	22.3
.77	9 1/4	2.41	3.49	4.58	6.77	8.97	13.6	18.2	22.7
.78	9 3/8	2.46	3.56	4.67	6.90	9.15	13.9	18.6	23.2
.79	9 1/2	2.51	3.63	4.76	7.04	9.33	14.2	18.9	23.6
.80	9 5/8	2.56	3.70	4.85	7.18	9.51	14.5	19.3	24.1
.81	9 3/4	2.61	3.77	4.95	7.31	9.69	14.7	19.6	24.5
.82	9 13/16	2.66	3.84	5.04	7.45	9.87	15.0	20.0	25.0
.83	9 15/16	2.71	3.92	5.14	7.59	10.0	15.3	20.4	25.5
.84	10 1/16	2.77	3.99	5.23	7.73	10.2	15.6	20.7	25.9
.85	10 3/16	2.82	4.07	5.33	7.87	10.4	15.8	21.1	26.4
.86	10 5/16	2.87	4.14	5.43	8.01	10.6	16.1	21.5	26.9
.87	10 7/16	2.93	4.22	5.52	8.15	10.8	16.4	21.9	27.3
.88	10 9/16	2.98	4.29	5.62	8.30	11.0	16.7	22.2	27.8
.89	10 11/16	3.04	4.37	5.72	8.44	11.2	17.0	22.6	28.3
.90	10 13/16	3.09	4.45	5.82	8.59	11.4	17.2	23.0	28.7
.91	10 15/16	3.15	4.53	5.92	8.73	11.6	17.5	23.4	29.2
.92	11 1/16	3.20	4.60	6.02	8.88	11.7	17.8	23.8	29.7
.93	11 1/16	3.26	4.68	6.13	9.03	11.9	18.1	24.2	30.2
.94	11 1/4	3.32	4.76	6.23	9.17	12.1	18.4	24.5	30.7
.95	11 3/8	3.37	4.84	6.33	9.32	12.3	18.7	24.9	31.2
.96	11 1/2	3.43	4.92	6.44	9.48	12.5	19.0	25.3	31.7
.97	11 5/8	3.49	5.00	6.55	9.62	12.7	19.3	25.7	32.2
.98	11 3/4	3.55	5.09	6.64	9.78	12.9	19.6	26.1	32.7
.99	11 7/8	3.61	5.17	6.75	9.93	13.1	19.9	26.5	33.2
1.00	12	3.67	5.25	6.86	10.1	13.3	20.2	26.9	33.7
1.01	12 1/8	------	5.33	6.96	10.2	13.5	20.5	27.3	34.2
1.02	12 1/4	------	5.42	7.07	10.4	13.7	20.8	27.7	34.7
1.03	12 3/8	------	5.50	7.18	10.6	13.9	21.1	28.2	35.2
1.04	12 1/2	------	5.59	7.29	10.7	14.2	21.4	28.6	35.7
1.05	12 5/8	------	5.67	7.40	10.9	14.4	21.7	29.0	36.2
1.06	12 3/4	------	5.76	7.51	11.0	14.6	22.0	29.4	36.7
1.07	12 13/16	------	5.84	7.62	11.2	14.8	22.4	29.8	37.3
1.08	12 15/16	------	5.93	7.73	11.4	15.0	22.7	30.2	37.8
1.09	13 1/16	------	6.02	7.84	11.5	15.2	23.0	30.6	38.3
1.10	13 3/16	------	6.11	7.96	11.7	15.4	23.3	31.1	38.8
1.11	13 5/16	------	6.20	8.07	11.8	15.6	23.6	31.5	39.4
1.12	13 7/16	------	6.29	8.18	12.0	15.8	23.9	31.9	39.9
1.13	13 9/16	------	6.38	8.29	12.2	16.0	24.3	32.4	40.4
1.14	13 11/16	------	6.47	8.41	12.3	16.3	24.6	32.8	41.0
1.15	13 13/16	------	6.56	8.53	12.5	16.5	24.9	33.2	41.5
1.16	13 15/16	------	6.65	8.65	12.7	16.7	25.2	33.6	42.1
1.17	14 1/16	------	6.74	8.76	12.8	16.9	25.6	34.1	42.6
1.18	14 1/16	------	6.83	8.88	13.0	17.2	25.9	34.5	43.2
1.19	14 1/4	------	6.93	9.00	13.2	17.4	26.2	35.0	43.7

See footenote at end of table.

Figure 16.11-2

Discharge table for Cipolletti weirs with complete contractions—Continued

Head, H[1]		Discharge, Q, for crest length, L, of—							
		1 foot	1.5 feet	2 feet	3 feet	4 feet	6 feet	8 feet	10 feet
Feet	*Inches*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
1. 20	14⅜	------	7. 02	9. 12	13. 4	17. 6	26. 6	35. 4	44. 3
1. 21	14½	------	7. 11	9. 24	13. 5	17. 8	26. 9	35. 8	44. 8
1. 22	14⅝	------	7. 20	9. 36	13. 7	18. 0	27. 2	36. 3	45. 4
1. 23	14¾	------	7. 30	9. 48	13. 9	18. 3	27. 6	36. 7	45. 9
1. 24	14⅞	------	7. 40	9. 60	14. 0	18. 5	27. 9	37. 2	46. 5
1. 25	15	------	7. 49	9. 72	14. 2	18. 7	28. 2	37. 6	47. 1
1. 26	15⅛	------	--------	--------	14. 4	19. 0	28. 6	38. 1	47. 6
1. 27	15¼	------	--------	--------	14. 6	19. 2	28. 9	38. 5	48. 2
1. 28	15⅜	------	--------	--------	14. 7	19. 4	29. 3	39. 0	48. 8
1. 29	15½	------	--------	--------	14. 9	19. 6	29. 6	39. 5	49. 3
1. 30	15⅝	------	--------	----------	15. 1	19. 9	29. 9	39. 9	49. 9
1. 31	15¾	------	--------	----------	15. 3	20. 1	30. 3	40. 4	50. 5
1. 32	15 13/16	------	--------	----------	15. 5	20. 3	30. 6	40. 8	51. 1
1. 33	15 15/16	------	--------	----------	15. 6	20. 6	31. 0	41. 3	51. 6
1. 34	16 1/16	------	--------	----------	15. 8	20. 8	31. 3	41. 8	52. 2
1. 35	16 3/16	------	--------	----------	16. 0	21. 1	31. 7	42. 2	52. 8
1. 36	16 5/16	------	--------	----------	16. 2	21. 3	32. 0	42. 7	53. 4
1. 37	16 7/16	------	--------	----------	16. 4	21. 5	32. 4	43. 2	54. 0
1. 38	16 9/16	------	--------	----------	16. 6	21. 8	32. 7	43. 7	54. 6
1. 39	16 11/16	------	--------	----------	16. 8	22. 0	33. 1	44. 1	55. 2
1. 40	16 13/16	------	--------	----------	16. 9	22. 3	33. 5	44. 6	55. 8
1. 41	16 15/16	------	--------	----------	17. 1	22. 5	33. 8	45. 1	56. 4
1. 42	17 1/16	------	--------	----------	17. 3	22. 8	34. 2	45. 6	57. 0
1. 43	17 3/16	------	--------	----------	17. 5	23. 0	34. 6	46. 1	57. 6
1. 44	17¼	------	--------	----------	17. 7	23. 3	34. 9	46. 5	58. 2
1. 45	17⅜	------	--------	--------	17. 9	23. 5	35. 3	47. 0	58. 8
1. 46	17½	------	--------	--------	18. 1	23. 8	35. 6	47. 5	59. 4
1. 47	17⅝	------	--------	--------	18. 3	24. 0	36. 0	48. 0	60. 0
1. 48	17¾	------	--------	--------	18. 5	24. 3	36. 4	48. 5	60. 6
1. 49	17⅞	------	--------	--------	18. 7	24. 5	36. 7	49. 0	61. 2
1. 50	18	------	--------	--------	18. 9	24. 8	37. 1	49. 5	61. 8

[1] Values of discharge for heads up to 0.20 foot (crest lengths 1, 1.5, 2, 3, and 4 feet) do not follow the formula but are taken directly from the calibration curve. The discharge for heads 0.10 to 1.5 feet for the 6-, 8,- and 10-foot weirs are as computed by the formula $Q=3.367LH^{3/2}$. See MEAD, E., and JOHNSTON, C. I. THE USE OF WATER IN IRRIGATION. U. S. Dept. Agr. Off. Expt. Sta. Bul. 86, 253 pp., illus. 1900.

Figure 16.11-3

Discharge table for 90° triangular-notch weir with complete contractions

Head, *H*		Discharge, *Q*	Head, *H*		Discharge, *Q*	Head, *H*		Discharge, *Q*
Feet	*Inches*	*Second-feet*	*Feet*	*Inches*	*Second-feet*	*Feet*	*Inches*	*Second-feet*
0.15	1 13/16	0.022	0.55	6 5/8	0.564	0.95	11 3/8	2.19
.16	1 15/16	.025	.56	6 3/4	.590	.96	11 1/2	2.25
.17	2 1/16	.029	.57	6 13/16	.617	.97	11 5/8	2.31
.18	2 3/16	.034	.58	6 15/16	.644	.98	11 3/4	2.37
.19	2 1/4	.040	.59	7 1/16	.672	.99	11 7/8	2.43
.20	2 3/8	.046	.60	7 1/16	.700	1.00	12	2.49
.21	2 1/2	.052	.61	7 5/16	.730	1.01	12 1/8	2.55
.22	2 5/8	.058	.62	7 7/16	.760	1.02	12 1/4	2.61
.23	2 3/4	.065	.63	7 9/16	.790	1.03	12 3/8	2.68
.24	2 7/8	.072	.64	7 11/16	.822	1.04	12 1/2	2.74
.25	3	.080	.65	7 13/16	.854	1.05	12 5/8	2.81
.26	3 1/8	.088	.66	7 15/16	.887	1.06	12 3/4	2.87
.27	3 1/4	.096	.67	8 1/16	.921	1.07	12 13/16	2.94
.28	3 3/8	.105	.68	8 3/16	.955	1.08	12 15/16	3.01
.29	3 1/2	.115	.69	8 1/4	.991	1.09	13 1/16	3.08
.30	3 5/8	.125	.70	8 3/8	1.03	1.10	13 3/16	3.15
.31	3 3/4	.136	.71	8 1/2	1.06	1.11	13 5/16	3.22
.32	3 13/16	.147	.72	8 5/8	1.10	1.12	13 7/16	3.30
.33	3 15/16	.159	.73	8 3/4	1.14	1.13	13 9/16	3.37
.34	4 1/16	.171	.74	8 7/8	1.18	1.14	13 11/16	3.44
.35	4 3/16	.184	.75	9	1.22	1.15	13 13/16	3.52
.36	4 5/16	.197	.76	9 1/8	1.26	1.16	13 15/16	3.59
.37	4 7/16	.211	.77	9 1/4	1.30	1.17	14 1/16	3.67
.38	4 9/16	.225	.78	9 3/8	1.34	1.18	14 3/16	3.75
.39	4 11/16	.240	.79	9 1/2	1.39	1.19	14 1/4	3.83
.40	4 13/16	.256	.80	9 5/8	1.43	1.20	14 3/8	3.91
.41	4 15/16	.272	.81	9 3/4	1.48	1.21	14 1/2	3.99
.42	5 1/16	.289	.82	9 13/16	1.52	1.22	14 5/8	4.07
.43	5 3/16	.306	.83	9 15/16	1.57	1.23	14 3/4	4.16
.44	5 1/4	.324	.84	10 1/16	1.61	1.24	14 7/8	4.24
.45	5 3/8	.343	.85	10 3/16	1.66	1.25	15	4.33
.46	5 1/2	.362	.86	10 5/16	1.71	1.26	15 1/8	4.42
.47	5 5/8	.382	.87	10 7/16	1.76	1.27	15 1/4	4.51
.48	5 3/4	.403	.88	10 9/16	1.81	1.28	15 3/8	4.60
.49	5 7/8	.424	.89	10 11/16	1.86	1.29	15 1/2	4.69
.50	6	.445	.90	10 13/16	1.92	1.30	15 5/8	4.78
.51	6 1/8	.468	.91	10 15/16	1.97	1.31	15 3/4	4.87
.52	6 1/4	.491	.92	11 1/16	2.02	1.32	15 13/16	4.96
.53	6 3/8	.515	.93	11 3/16	2.08	1.33	15 15/16	5.06
.54	6 1/2	.539	.94	11 1/4	2.13	1.34	16 1/16	5.15

Figure 16.12

3. WEIR FLOW (CONT'D)

Use and Limitations (cont'd)

Cippoletti and Triangular Notch Weirs (cont'd)

approaching stream channel should be at least six times the area of the weir section.

Silt must be cleared away from the front of the weir to a depth equal to twice the value of "H" to permit normal bottom contraction.

The Parshall Flume. This is another measuring device that is widely used for measuring quantity of water flowing in open channels.

It has been found by experience to be well adapted to measuring both large and small flows. The device consists of a converging section with level floor, a throat section with floor sloping downstream, and a diverging section with floor sloping upstream. Walls throughout the structure are vertical. Flow through the parshall flume is not significantly affected by channel approach conditions.

For individual farm use, the parshall flume is better adapted than the weir because: (1) It is capable of automatically keeping itself free from the effects of sand or silt under nearly all operating conditions. (2) It operates satisfactorily with small loss of head. (3) It is comparatively inexpensive to install.

Successful operation of the parshall flume depends upon setting the crest at the correct elevation with respect to the bed of the channel. Figure 16.13 shows a longitudinal section of this flume.

H_a = difference in elevation between upstream water surface and crest level of flume.

H_b = difference in elevation between downstream water surface and crest level of flume.

X = difference in elevation between bottom of ditch at lower end and crest level of flume.

D = depth of water in ditch below flume.

L = difference in elevation between water surfaces above and below flume.

Where sufficient fall is available, this setting may be determined with little difficulty, but if the fall is slight, care must be taken in fixing the height of the crest so that the degree of submergence shall not exceed the limits of free flow. This limit is .70 for flumes having a throat width of one foot or more, and .60 for flumes having a throat width of less than one foot. In other words, H_b shall not exceed .70 H_a or .60 H_a as the case may be. Other settings using a greater degree of submergence can be

3. WEIR FLOW (CONT'D)

Use and Limitations (cont'd)

The Parshall Flume (cont'd)

made, but the reading of two gauges is required and the procedure is more complicated. Information on submerged flow can be found in USDA Farmers Bulletin #1683. Figures 16.14-1 through 6 give the flow of water through parshall flumes. Figure 16.15 gives the loss of head for the "Parshall Flume".

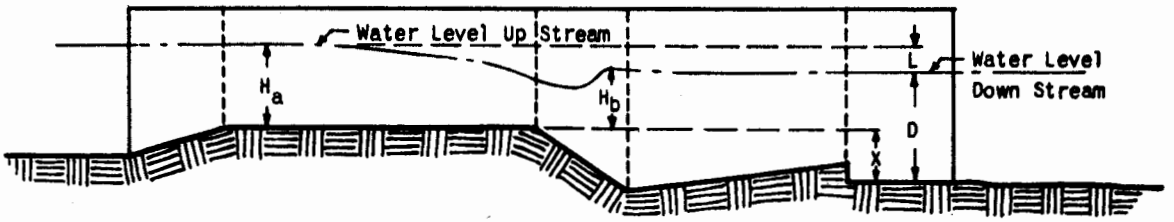


Figure 16.13

To determine the proper elevation above the ditch bottom for setting the parshall flume, the following outline should be used:

Example: A ditch has a maximum capacity of about 6 cubic feet per second when flowing at a depth of about 1.5 feet. Determine size and setting of flume to be used.

1. From Figure 16.14 select a flume that will deliver 6 cubic feet per second when flowing at a depth of 1.5 feet or less. In this case, a one-foot flume with a head (H_a) of 1.31 feet will deliver 6 c.f.s.

2. Using a submergence of 0.7, we find (H_b) to equal 1.31 x 0.7 = 0.92.

3. From Figure 16.13, (X) (the setting above stream bed) is ($D - H_b$) or 1.5 - 0.92 = 0.58.

To determine the depth of flow above the flume, select the value for the loss of head (L) from Figure 16.15 and add to the original depth. In this case, the loss of head is 0.41 feet. Therefore, 1.5 + .41 = 1.91 which is the depth of water above the flume.

The height of the ditch banks above the proposed location of the flume should be examined to determine whether or not they will be over-topped. Other flumes should be considered to determine the size best suited for any given condition.

FREE FLOW THROUGH SMALL PARSHALL MEASURING FLUME

HEAD	DISCHARGE 2" THROAT (GALVANIZED)		DISCHARGE 1" THROAT (GALVANIZED & ALUMINUM)	
Inches	c.f.s.	g.p.m.	c.f.s.	g.p.m.
1/2	.0042	1.9	.0020	.9
5/8	.0054	2.4	.0030	1.3
3/4	.0070	3.1	.0040	1.8
7/8	.0090	4.0	.0055	2.5
1	.0112	5.0	.0070	3.1
1 1/8	.0140	6.3	.0090	4.0
1 1/4	.0170	7.6	.0106	4.8
1 3/8	.0205	9.2	.0125	5.6
1 1/2	.0248	11.1	.0141	6.3
1 5/8	.0287	12.9	.0160	7.2
1 3/4	.0330	14.8	.0180	8.1
1 7/8	.0370	16.6	.0200	9.0
2	.0416	18.7	.0225	10.1
2 1/8	.0460	20.6	.0250	11.2
2 1/4	.0500	22.4	.0274	12.3
2 3/8	.0540	24.2	.0296	13.3
2 1/2	.0580	26.0	.0320	14.4
2 5/8	.0620	27.8	.0350	15.7
2 3/4	.0660	29.6	.0375	16.8
2 7/8	.0700	31.4	.0405	18.2
3	.0743	33.3	.0435	19.5
3 1/8	.0785	35.2	.0460	20.6
3 1/4	.0830	37.3	.0490	22.0
3 3/8	.0870	39.0	.0520	23.3
3 1/2	.0922	41.4	.0550	24.7
3 5/8	.0980	44.0	.0575	25.8
3 3/4	.1046	46.9	.0606	27.2
3 7/8	.1118	50.2	.0635	28.5
4	.1200	53.9	.0668	30.0
4 1/8	.1300	58.3	.0700	31.4
4 1/4	.1400	62.8	.0750	33.7
4 3/8	---		.0800	35.9
4 1/2	---		.0840	37.7

NOTE: In calibrating, standard flumes and those having no diverging section were used. In every case flow was the same through each type. One inch flumes were constructed of galvanized iron as well as aluminum. Flow through these two types of metal did not vary. It should be noted that the flow is considerably reduced when the flumes are not cleaned of excess asphalt cement.

Figure 16.14-1

FREE FLOW DISCHARGE TABLE FOR PARSHALL FLUMES

Head, H_a (feet)	Discharge, Q, for throat widths, W, of—											
	3 inches	6 inches	9 inches	1 foot	1.5 feet	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet
	Second-feet	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0.10	0.028	0.05	0.09	0.11	0.15	-----	-----	-----	-----	-----	-----	-----
.11	.033	.06	.10	.12	.18	-----	-----	-----	-----	-----	-----	-----
.12	.037	.07	.12	.14	.21	-----	-----	-----	-----	-----	-----	-----
.13	.042	.08	.14	.16	.24	-----	-----	-----	-----	-----	-----	-----
.14	.047	.09	.15	.18	.27	-----	-----	-----	-----	-----	-----	-----
.15	.053	.10	.17	.20	.30	0.42	0.61	-----	-----	-----	-----	-----
.16	.058	.11	.19	.23	.34	.47	.68	-----	-----	-----	-----	-----
.17	.064	.12	.20	.26	.38	.51	.75	-----	-----	-----	-----	-----
.18	.070	.14	.22	.29	.42	.56	.82	-----	-----	-----	-----	-----
.19	.076	.15	.24	.32	.46	.61	.89	-----	-----	-----	-----	-----
.20	.082	.16	.26	.35	.51	.66	.97	1.26	1.55	-----	-----	-----
.21	.089	.18	.28	.37	.55	.71	1.04	1.36	1.68	-----	-----	-----
.22	.095	.19	.30	.40	.59	.77	1.12	1.47	1.81	-----	-----	-----
.23	.102	.20	.32	.43	.63	.82	1.20	1.58	1.94	-----	-----	-----
.24	.109	.22	.35	.46	.67	.88	1.28	1.69	2.08	-----	-----	-----
.25	.117	.23	.37	.49	.71	.93	1.37	1.80	2.22	2.63	3.02	3.46
.26	.124	.25	.39	.51	.76	.99	1.46	1.91	2.36	2.80	3.25	3.68
.27	.131	.26	.41	.54	.80	1.05	1.55	2.03	2.50	2.97	3.44	3.90
.28	.138	.28	.44	.58	.85	1.11	1.64	2.15	2.65	3.15	3.65	4.13
.29	.146	.29	.46	.61	.90	1.18	1.73	2.27	2.80	3.33	3.85	4.37
.30	.154	.31	.49	.64	.94	1.24	1.82	2.39	2.96	3.52	4.08	4.62
.31	.162	.32	.51	.68	.99	1.30	1.92	2.52	3.12	3.71	4.30	4.88
.32	.170	.34	.54	.71	1.04	1.37	2.02	2.65	3.28	3.90	4.52	5.13
.33	.179	.36	.56	.74	1.09	1.44	2.12	2.78	3.44	4.10	4.75	5.39
.34	.187	.38	.59	.77	1.14	1.50	2.22	2.92	3.61	4.30	4.98	5.66
.35	.196	.39	.62	.80	1.19	1.57	2.32	3.06	3.78	4.50	5.22	5.93
.36	.205	.41	.64	.84	1.25	1.64	2.42	3.20	3.95	4.71	5.46	6.20
.37	.213	.43	.67	.88	1.30	1.72	2.53	3.34	4.13	4.92	5.70	6.48
.38	.222	.45	.70	.92	1.36	1.79	2.64	3.48	4.31	5.13	5.95	6.76
.39	.231	.47	.73	.95	1.41	1.86	2.75	3.62	4.49	5.35	6.20	7.05
.40	.241	.48	.76	.99	1.47	1.93	2.86	3.77	4.68	5.57	6.46	7.34
.41	.250	.50	.78	1.03	1.53	2.01	2.97	3.92	4.86	5.80	6.72	7.64
.42	.260	.52	.81	1.07	1.58	2.09	3.08	4.07	5.05	6.02	6.98	7.94
.43	.269	.54	.84	1.11	1.64	2.16	3.29	4.22	5.24	6.25	7.25	8.24
.44	.279	.56	.87	1.15	1.70	2.24	3.32	4.38	5.43	6.48	7.52	8.55
.45	.289	.58	.90	1.19	1.76	2.32	3.44	4.54	5.63	6.72	7.80	8.87
.46	.299	.61	.94	1.23	1.82	2.40	3.56	4.70	5.83	6.96	8.08	9.19
.47	.309	.63	.97	1.27	1.88	2.48	3.68	4.86	6.03	7.20	8.36	9.51
.48	.319	.65	1.00	1.31	1.94	2.57	3.80	5.03	6.24	7.44	8.65	9.84
.49	.329	.67	1.03	1.35	2.00	2.65	3.92	5.20	6.45	7.69	8.94	10.2
.50	.339	.69	1.06	1.39	2.06	2.73	4.05	5.36	6.66	7.94	9.23	10.5
.51	.350	.71	1.10	1.44	2.13	2.82	4.18	5.53	6.87	8.20	9.53	10.9
.52	.361	.73	1.13	1.48	2.19	2.90	4.31	5.70	7.09	8.46	9.83	11.2
.53	.371	.76	1.16	1.52	2.25	2.99	4.44	5.88	7.30	8.72	10.1	11.5
.54	.382	.78	1.20	1.57	2.32	3.08	4.57	6.05	7.52	8.98	10.5	11.9
.55	.393	.80	1.23	1.62	2.39	3.17	4.70	6.23	7.74	9.25	10.8	12.2
.56	.404	.82	1.26	1.66	2.45	3.26	4.84	6.41	7.97	9.52	11.1	12.6
.57	.415	.85	1.30	1.70	2.52	3.35	4.98	6.59	8.20	9.79	11.4	13.0
.58	.427	.87	1.33	1.75	2.59	3.44	5.11	6.77	8.43	10.1	11.7	13.3
.59	.438	.89	1.37	1.80	2.66	3.53	5.25	6.96	8.66	10.4	12.0	13.7

Note: Discharges are for 60% submergence or less for throat widths less than one foot, and 70% submergence or less for throat widths of one to eight feet.

Figure 16.14-2

Head, H_a (feet)	Discharge, Q, for throat widths, W, of—											
	3 inches	6 inches	9 inches	1 foot	1.5 feet	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet
	Second-feet	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
0.60	0.450	0.92	1.40	1.84	2.73	3.62	5.39	7.15	8.89	10.6	12.4	14.1
.61	.462	.94	1.44	1.88	2.80	3.72	5.53	7.34	9.13	10.9	12.7	14.5
.62	.474	.97	1.48	1.93	2.87	3.81	5.68	7.53	9.37	11.2	13.0	14.8
.63	.485	.99	1.51	1.98	2.95	3.91	5.82	7.72	9.61	11.5	13.4	15.2
.64	.497	1.02	1.55	2.03	3.02	4.01	5.97	7.91	9.85	11.8	13.7	15.6
.65	.509	1.04	1.59	2.08	3.09	4.11	6.12	8.11	10.1	12.1	14.1	16.0
.66	.522	1.07	1.63	2.13	3.17	4.20	6.26	8.31	10.3	12.4	14.4	16.4
.67	.534	1.10	1.66	2.18	3.24	4.30	6.41	8.51	10.6	12.7	14.8	16.8
.68	.546	1.12	1.70	2.23	3.31	4.40	6.56	8.71	10.8	13.0	15.1	17.2
.69	.558	1.15	1.74	2.28	3.39	4.50	6.71	8.91	11.1	13.3	15.5	17.6
.70	.571	1.17	1.78	2.33	3.46	4.60	6.86	9.11	11.4	13.6	15.8	18.0
.71	.584	1.20	1.82	2.38	3.54	4.70	7.02	9.32	11.6	13.9	16.2	18.5
.72	.597	1.23	1.86	2.43	3.62	4.81	7.17	9.53	11.9	14.2	16.6	18.9
.73	.610	1.26	1.90	2.48	3.69	4.91	7.33	9.74	12.1	14.5	16.9	19.3
.74	.623	1.28	1.94	2.53	3.77	5.02	7.49	9.95	12.4	14.9	17.3	19.7
.75	.636	1.31	1.98	2.58	3.85	5.12	7.65	10.2	12.7	15.2	17.7	20.1
.76	.649	1.34	2.02	2.63	3.93	5.23	7.81	10.4	12.9	15.5	18.0	20.6
.77	.662	1.36	2.06	2.68	4.01	5.34	7.97	10.6	13.2	15.8	18.4	21.0
.78	.675	1.39	2.10	2.74	4.09	5.44	8.13	10.8	13.5	16.2	18.8	21.5
.79	.689	1.42	2.14	2.80	4.17	5.55	8.30	11.0	13.8	16.5	19.2	21.9
.80	.702	1.45	2.18	2.85	4.26	5.66	8.46	11.3	14.0	16.8	19.6	22.4
.81	.716	1.48	2.22	2.90	4.34	5.77	8.63	11.5	14.3	17.2	20.0	22.8
.82	.730	1.50	2.27	2.96	4.42	5.88	8.79	11.7	14.6	17.5	20.4	23.3
.83	.744	1.53	2.31	3.02	4.50	6.00	8.96	11.9	14.9	17.8	20.8	23.7
.84	.757	1.56	2.35	3.07	4.59	6.11	9.13	12.2	15.2	18.2	21.2	24.2
.85	.771	1.59	2.39	3.12	4.67	6.22	9.30	12.4	15.5	18.5	21.6	24.6
.86	.786	1.62	2.44	3.18	4.76	6.33	9.48	12.6	15.8	18.9	22.0	25.1
.87	.800	1.65	2.48	3.24	4.84	6.44	9.65	12.8	16.0	19.2	22.4	25.6
.88	.814	1.68	2.52	3.29	4.93	6.56	9.82	13.1	16.3	19.6	22.8	26.1
.89	.828	1.71	2.57	3.35	5.01	6.68	10.0	13.3	16.6	19.9	23.2	26.5
.90	.843	1.74	2.61	3.41	5.10	6.80	10.2	13.6	16.9	20.3	23.7	27.0
.91	.858	1.77	2.66	3.46	5.19	6.92	10.4	13.8	17.2	20.7	24.1	27.5
.92	.872	1.81	2.70	3.52	5.28	7.03	10.5	14.0	17.5	21.0	24.5	28.0
.93	.887	1.84	2.75	3.58	5.37	7.15	10.7	14.3	17.8	21.4	24.9	28.5
.94	.902	1.87	2.79	3.64	5.46	7.27	10.9	14.5	18.1	21.8	25.4	29.0
.95	.916	1.90	2.84	3.70	5.55	7.39	11.1	14.8	18.4	22.1	25.8	29.5
.96	.931	1.93	2.88	3.76	5.64	7.51	11.3	15.0	18.8	22.5	26.2	30.0
.97	.946	1.97	2.93	3.82	5.73	7.63	11.4	15.3	19.1	22.9	26.7	30.5
.98	.961	2.00	2.98	3.88	5.82	7.75	11.6	15.5	19.4	23.2	27.1	31.0
.99	.977	2.03	3.02	3.94	5.91	7.88	11.8	15.8	19.7	23.6	27.6	31.5
1.00	.992	2.06	3.07	4.00	6.00	8.00	12.0	16.0	20.0	24.0	28.0	32.0
1.01	1.01	2.09	3.12	4.06	6.09	8.12	12.2	16.3	20.3	24.4	28.5	32.5
1.02	1.02	2.12	3.17	4.12	6.19	8.25	12.4	16.5	20.6	24.8	28.9	33.0
1.03	1.04	2.16	3.21	4.18	6.28	8.38	12.6	16.8	21.0	25.2	29.4	33.6
1.04	1.05	2.19	3.26	4.25	6.37	8.50	12.8	17.0	21.3	25.6	29.8	34.1
1.05	1.07	2.22	3.31	4.31	6.47	8.63	13.0	17.3	21.6	25.9	30.3	34.6
1.06	1.09	2.26	3.36	4.37	6.56	8.76	13.2	17.5	21.9	26.3	30.7	35.1
1.07	1.10	2.29	3.40	4.43	6.66	8.88	13.3	17.8	22.3	26.7	31.2	35.7
1.08	1.12	2.32	3.45	4.50	6.75	9.01	13.5	18.1	22.6	27.1	31.7	36.2
1.09	1.13	2.36	3.50	4.56	6.85	9.14	13.7	18.3	22.9	27.5	32.1	36.8

Figure 16.14-3

Head, H_a (feet)	Discharge, Q, for throat widths, W, of—											
	3 inches	6 inches	9 inches	1 foot	1.5 feet	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet
	Second-feet	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
1.10	1.15	2.40	3.55	4.62	6.95	9.27	13.9	18.6	23.3	27.9	32.6	37.3
1.11	1.16	2.43	3.60	4.68	7.04	9.40	14.1	18.9	23.6	28.4	33.1	37.8
1.12	1.18	2.46	3.65	4.75	7.14	9.54	14.3	19.1	23.9	28.8	33.6	38.4
1.13	1.20	2.50	3.70	4.82	7.24	9.67	14.5	19.4	24.3	29.2	34.1	38.9
1.14	1.21	2.53	3.75	4.88	7.34	9.80	14.7	19.7	24.6	29.6	34.5	39.5
1.15	1.22	2.57	3.80	4.94	7.44	9.94	14.9	19.9	25.0	30.0	35.0	40.1
1.16	1.25	2.60	3.85	5.01	7.54	10.1	15.1	20.2	25.3	30.4	35.5	40.6
1.17	1.26	2.64	3.90	5.08	7.64	10.2	15.3	20.5	25.7	30.8	36.0	41.2
1.18	1.28	2.68	3.95	5.15	7.74	10.3	15.6	20.8	26.0	31.3	36.5	41.8
1.19	1.30	2.71	4.01	5.21	7.84	10.5	15.8	21.1	26.4	31.7	37.0	42.3
1.20	1.32	2.75	4.06	5.28	7.94	10.6	16.0	21.3	26.7	32.1	37.5	42.9
1.21	1.33	2.78	4.11	5.34	8.05	10.8	16.2	21.6	27.1	32.5	38.0	43.5
1.22	1.35	2.82	4.16	5.41	8.15	10.9	16.4	21.9	27.4	33.0	38.5	44.1
1.23	1.37	2.86	4.22	5.48	8.25	11.0	16.6	22.2	27.8	33.4	39.0	44.6
1.24	1.38	2.89	4.27	5.55	8.36	11.2	16.8	22.5	28.1	33.8	39.5	45.2
1.25	1.40	2.93	4.32	5.62	8.46	11.3	17.0	22.8	28.5	34.3	40.0	45.8
1.26	1.42	2.97	4.37	5.69	8.56	11.5	17.2	23.0	28.9	34.7	40.5	46.4
1.27	1.44	3.01	4.43	5.76	8.67	11.6	17.4	23.3	29.2	35.1	41.1	47.0
1.28	1.45	3.04	4.48	5.82	8.77	11.7	17.7	23.6	29.6	35.6	41.6	47.6
1.29	1.47	3.08	4.53	5.89	8.88	11.9	17.9	23.9	30.0	36.0	42.1	48.2
1.30	1.49	3.12	4.59	5.96	8.99	12.0	18.1	24.2	30.3	36.5	42.6	48.8
1.31	1.50	3.16	4.64	6.03	9.09	12.2	18.3	24.5	30.7	36.9	43.1	49.4
1.32	1.52	3.19	4.69	6.10	9.20	12.3	18.5	24.8	31.1	37.4	43.7	50.0
1.33	1.54	3.23	4.75	6.18	9.30	12.4	18.8	25.1	31.4	37.8	44.2	50.6
1.34	1.56	3.27	4.80	6.25	9.41	12.6	19.0	25.4	31.8	38.3	44.7	51.2
1.35	1.58	3.31	4.86	6.32	9.52	12.7	19.2	25.7	32.2	38.7	45.3	51.8
1.36	1.59	3.35	4.92	6.39	9.63	12.9	19.4	26.0	32.6	39.2	45.8	52.5
1.37	1.61	3.39	4.97	6.46	9.74	13.0	19.6	26.3	33.0	39.7	46.4	53.1
1.38	1.63	3.43	5.03	6.53	9.85	13.2	19.9	26.6	33.3	40.1	46.9	53.7
1.39	1.65	3.47	5.08	6.60	9.96	13.3	20.1	26.9	33.7	40.6	47.4	54.3
1.40	1.67	3.51	5.14	6.68	10.1	13.5	20.3	27.2	34.1	41.1	48.0	55.0
1.41	1.69	3.55	5.19	6.75	10.2	13.6	20.6	27.5	34.5	41.5	48.5	55.6
1.42	1.70	3.59	5.25	6.82	10.3	13.8	20.8	27.8	34.9	42.0	49.1	56.2
1.43	1.72	3.63	5.31	6.89	10.4	13.9	21.0	28.1	35.3	42.5	49.6	56.9
1.44	1.74	3.67	5.37	6.97	10.5	14.1	21.2	28.5	35.7	42.9	50.2	57.5
1.45	1.76	3.71	5.42	7.04	10.6	14.2	21.5	28.8	36.1	43.4	50.8	58.1
1.46	1.78	3.75	5.48	7.12	10.7	14.4	21.7	29.1	36.5	43.9	51.3	58.8
1.47	1.80	3.79	5.54	7.19	10.8	14.5	21.9	29.4	36.9	44.4	51.9	59.4
1.48	1.82	3.83	5.59	7.26	11.0	14.7	22.2	29.7	37.3	44.9	52.5	60.1
1.49	1.84	3.87	5.65	7.34	11.1	14.9	22.4	30.0	37.7	45.3	53.0	60.7
1.50	1.86	3.91	5.71	7.41	11.2	15.0	22.6	30.3	38.1	45.8	53.6	61.4
1.51	----	----	5.77	7.49	11.3	15.2	22.9	30.7	38.5	46.3	54.2	62.1
1.52	----	----	5.83	7.57	11.4	15.3	23.1	31.0	38.9	46.8	54.7	62.7
1.53	----	----	5.89	7.64	11.5	15.5	23.4	31.3	39.3	47.3	55.3	63.4
1.54	----	----	5.94	7.72	11.7	15.6	23.6	31.6	39.7	47.8	55.9	64.0
1.55	----	----	6.00	7.80	11.8	15.8	23.8	32.0	40.1	48.3	56.5	64.7
1.56	----	----	6.06	7.87	11.9	15.9	24.1	32.3	40.5	48.8	57.1	65.4
1.57	----	----	6.12	7.95	12.0	16.1	24.3	32.6	40.9	49.3	57.7	66.1
1.58	----	----	6.18	8.02	12.1	16.3	24.6	32.9	41.3	49.8	58.2	66.7
1.59	----	----	6.24	8.10	12.2	16.4	24.8	33.3	41.8	50.3	58.8	67.4

Figure 16.14-4

Head, H_a (feet)	Discharge, Q, for throat widths, W, of—											
	3 inches	6 inches	9 inches	1 foot	1.5 feet	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet
	Second-feet	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
1.60	----	----	6.31	8.18	12.4	16.6	25.1	33.6	42.2	50.8	59.4	68.1
1.61	----	----	6.37	8.26	12.5	16.7	25.3	33.9	42.6	51.3	60.0	68.8
1.62	----	----	6.43	8.34	12.6	16.9	25.5	34.3	43.0	51.8	60.6	69.5
1.63	----	----	6.49	8.42	12.7	17.1	25.8	34.6	43.4	52.3	61.2	70.2
1.64	----	----	6.55	8.49	12.8	17.2	26.0	34.9	43.9	52.8	61.8	70.9
1.65	----	----	6.61	8.57	13.0	17.4	26.3	35.3	44.3	53.3	62.4	71.6
1.66	----	----	6.67	8.65	13.1	17.6	26.5	35.6	44.7	53.9	63.0	72.3
1.67	----	----	6.73	8.73	13.2	17.7	26.8	35.9	45.1	54.4	63.6	73.0
1.68	----	----	6.79	8.81	13.3	17.9	27.0	36.3	45.6	54.9	64.3	73.7
1.69	----	----	6.86	8.89	13.5	18.0	27.3	36.6	46.0	55.4	64.9	74.4
1.70	----	----	6.92	8.97	13.6	18.2	27.6	37.0	46.4	56.0	65.5	75.1
1.71	----	----	6.98	9.05	13.7	18.4	27.8	37.3	46.9	56.5	66.1	75.8
1.72	----	----	7.04	9.13	13.8	18.5	28.1	37.7	47.3	57.0	66.7	76.5
1.73	----	----	7.11	9.21	13.9	18.7	28.3	38.0	47.7	57.5	67.3	77.2
1.74	----	----	7.17	9.29	14.1	18.9	28.6	38.3	48.2	58.1	68.0	77.9
1.75	----	----	7.23	9.38	14.2	19.0	28.8	38.7	48.6	58.6	68.6	78.7
1.76	----	----	7.29	9.46	14.3	19.2	29.1	39.0	49.1	59.1	69.2	79.4
1.77	----	----	7.36	9.54	14.4	19.4	29.3	39.4	49.5	59.7	69.9	80.1
1.78	----	----	7.42	9.62	14.6	19.6	29.6	39.7	49.9	60.2	70.5	80.8
1.79	----	----	7.48	9.70	14.7	19.7	29.9	40.1	50.4	60.7	71.1	81.6
1.80	----	----	7.54	9.79	14.8	19.9	30.1	40.5	50.8	61.3	71.8	82.3
1.81	----	----	7.61	9.87	15.0	20.1	30.4	40.8	51.3	61.8	72.4	83.0
1.82	----	----	7.68	9.95	15.1	20.2	30.7	41.2	51.7	62.4	73.0	83.8
1.83	----	----	7.74	10.0	15.2	20.4	30.9	41.5	52.2	62.9	73.7	84.5
1.84	----	----	7.81	10.1	15.3	20.6	31.2	41.9	52.6	63.5	74.3	85,3
1.85	----	----	7.87	10.2	15.5	20.8	31.5	42.2	53.1	64.0	75.0	86.0
1.86	----	----	7.94	10.3	15.6	20.9	31.7	42.6	53.6	64.6	75.6	86.8
1.87	----	----	8.00	10.4	15.7	21.1	32.0	43.0	54.0	65.1	76.3	87.5
1.88	----	----	8.06	10.5	15.8	21.3	32.3	43.3	54.5	65.7	76.9	88.3
1.89	----	----	8.13	10.5	16.0	21.5	32.5	43.7	54.9	66.3	77.6	89.0
1.90	----	----	8.20	10.6	16.1	21.6	32.8	44.1	55.4	66.8	78.2	89.8
1.91	----	----	8.26	10.7	16.2	21.8	33.1	44.4	55.9	67.4	78.9	90.5
1.92	----	----	8.33	10.8	16.4	22.0	33.3	44.8	56.3	67.9	79.6	91.3
1.93	----	----	8.40	10.9	16.5	22.2	33.6	45.2	56.8	68.5	80.2	92.1
1.94	----	----	8.46	11.0	16.6	22.4	33.9	45.5	57.3	69.1	80.9	92.8
1.95	----	----	8.52	11.1	16.7	22.5	34.1	45.9	57.7	69.6	81.6	93.6
1.96	----	----	8.59	11.1	16.9	22.7	34.4	46.3	58.2	70.2	82.2	94.4
1.97	----	----	8.66	11.2	17.0	22.9	34.7	46.6	58.7	70.8	82.9	95.1
1.98	----	----	8.73	11.3	17.2	23.1	35.0	47.0	59.1	71.4	83.6	95.9
1.99	----	----	8.80	11.4	17.3	23.2	35.3	47.4	59.6	71.9	84.3	96.7
2.00	----	----	8.87	11.5	17.4	23.4	35.5	47.8	60.1	72.5	84.9	97.5
2.01	----	----	----	11.6	17.6	23.6	35.8	48.1	60.6	73.1	85.6	98.3
2.02	----	----	----	11.7	17.7	23.8	36.1	48.5	61.0	73.7	86.3	99.1
2.03	----	----	----	11.8	17.8	24.0	36.4	48.9	61.5	74.2	87.0	99.8
2.04	----	----	----	11.8	18.0	24.2	36.7	49.3	62.0	74.8	87.7	100.6
2.05	----	----	----	11.9	18.1	24.3	36.9	49.7	62.5	75.4	88.4	101.4
2.06	----	----	----	12.0	18.2	24.5	37.2	50.1	63.0	76.0	89.1	102.2
2.07	----	----	----	12.1	18.4	24.7	37.5	50.4	63.5	76.6	89.8	103.0
2.08	----	----	----	12.2	18.5	24.9	37.8	50.8	63.9	77.2	90.4	103.8
2.09	----	----	----	12.3	18.7	25.1	38.1	51.2	64.4	77.8	91.1	104.6

Figure 16.14-5

Head, H_a (feet)	Discharge, Q, for throat widths, W, of—											
	3 inches	6 inches	9 inches	1 foot	1.5 feet	2 feet	3 feet	4 feet	5 feet	6 feet	7 feet	8 feet
	Second-feet	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*	*Second-feet*
2.10	----	----	----	12.4	18.8	25.3	38.4	51.6	64.9	78.4	91.8	105.4
2.11	----	----	----	12.5	18.9	25.5	38.6	52.0	65.4	79.0	92.5	106.2
2.12	----	----	----	12.6	19.0	25.6	38.9	52.4	65.9	79.6	93.3	107.0
2.13	----	----	----	12.6	19.2	25.8	39.2	52.8	66.4	80.2	94.0	107.9
2.14	----	----	----	12.7	19.3	26.0	39.5	53.2	66.9	80.8	94.7	108.7
2.15	----	----	----	12.8	19.5	26.2	39.8	53.5	67.4	81.4	95.4	109.5
2.16	----	----	----	12.9	19.6	26.4	40.1	53.9	67.9	82.0	96.1	110.3
2.17	----	----	----	13.0	19.7	26.6	40.4	54.3	68.4	82.6	96.8	111.1
2.18	----	----	----	13.1	19.9	26.8	40.7	54.7	68.9	83.2	97.5	111.9
2.19	----	----	----	13.2	20.0	27.0	41.0	55.1	69.4	83.8	98.2	112.8
2.20	----	----	----	13.3	20.2	27.2	41.3	55.5	69.9	84.4	98.9	113.6
2.21	----	----	----	13.4	20.3	27.3	41.5	55.9	70.4	85.0	99.7	114.4
2.22	----	----	----	13.5	20.5	27.5	41.8	56.3	70.9	85.6	100.4	115.3
2.23	----	----	----	13.6	20.6	27.7	42.1	56.7	71.4	86.3	101.1	116.1
2.24	----	----	----	13.7	20.7	27.9	42.4	57.1	71.9	86.9	101.8	116.9
2.25	----	----	----	13.7	20.9	28.1	42.7	57.5	72.4	87.5	102.6	117.8
2.26	----	----	----	13.8	21.0	28.3	43.0	57.9	72.9	88.1	103.3	118.6
2.27	----	----	----	13.9	21.2	28.5	43.3	58.3	73.5	88.7	104.0	119.5
2.28	----	----	----	14.0	21.3	28.7	43.6	58.7	74.0	89.4	104.8	120.3
2.29	----	----	----	14.1	21.4	28.9	43.9	59.2	74.5	90.0	105.5	121.2
2.30	----	----	----	14.2	21.6	29.1	44.2	59.6	75.0	90.6	106.2	122.0
2.31	----	----	----	14.3	21.7	29.3	44.5	60.0	75.5	91.2	107.0	122.9
2.32	----	----	----	14.4	21.9	29.5	44.8	60.4	76.1	91.9	107.7	123.7
2.33	----	----	----	14.5	22.0	29.7	45.1	60.8	76.6	92.5	108.5	124.6
2.34	----	----	----	14.6	22.2	29.9	45.4	61.2	77.1	93.1	109.2	125.4
2.35	----	----	----	14.7	22.4	30.1	45.7	61.6	77.6	93.8	110.0	126.3
2.36	----	----	----	14.8	22.5	30.3	46.0	62.0	78.1	94.4	110.7	127.2
2.37	----	----	----	14.9	22.6	30.5	46.4	62.4	78.7	95.1	111.5	128.0
2.38	----	----	----	15.0	22.8	30.7	46.7	62.9	79.2	95.7	112.2	128.9
2.39	----	----	----	15.1	22.9	30.9	47.0	63.3	79.7	96.3	113.0	129.8
2.40	----	----	----	15.2	23.0	31.1	47.3	63.7	80.3	97.0	113.7	130.7
2.41	----	----	----	15.3	23.2	31.3	47.6	64.1	80.8	97.6	114.5	131.5
2.42	----	----	----	15.4	23.3	31.5	47.9	64.5	81.3	98.3	115.3	132.4
2.43	----	----	----	15.5	23.5	31.7	48.2	65.0	81.8	98.9	116.0	133.3
2.44	----	----	----	15.6	23.7	31.9	48.5	65.4	82.4	99.6	116.8	134.2
2.45	----	----	----	15.6	23.8	32.1	48.8	65.8	82.9	100.2	117.6	135.1
2.46	----	----	----	15.7	23.9	32.3	49.1	66.2	83.5	100.9	118.3	135.9
2.47	----	----	----	15.9	24.1	32.5	49.5	66.7	84.0	101.5	119.1	136.8
2.48	----	----	----	15.9	24.2	32.7	49.8	67.1	84.5	102.2	119.9	137.7
2.49	----	----	----	16.0	24.4	32.9	50.1	67.5	85.1	102.8	120.6	138.6
2.50	----	----	----	16.1	24.6	33.1	50.4	67.9	85.6	103.5	121.4	139.5

Figure 16.14-6

TABLE SHOWING MINIMUM HEAD LOSS THROUGH
A PARSHALL FLUME WITH FREE FLOW CONDITIONS

Discharge in c.f.s.	Loss of Head in Flume			
	6"	9"	12"	18"
.1	.05	.00	...	...
.3	.09	.05	.06	.04
.5	.16	.09	.08	.07
.75	.20	.13	.12	.09
1.0	.25	.17	.14	.11
2.0	.43	.32	.22	.17
3.0	.59	.47	.27	.22
4.0	...	.58	.34	.26
5.0	...	.70	.38	.30
6.0	...	.80	.42	.33
7.0	...	.97	.48	.37
8.0	...	...	.54	.41
9.0	...	...	.58	.45
10.0	...	...	.62	.48
12.0	...	...	.68	.52
14.0	...	...	.76	.60
16.0	...	...	.83	.68
18.0	...	...	...	.72
20.0	...	...	...	.77
25.0	...	...	...	.85

Figure 16.15

Note:

Losses figured for percentage of submergence of 60% throat widths 6" and 9" and 70% for throat widths of 12" and 18". For losses for other throat width or percentage of submergence, consult Farmers Bulletin No. 1683, U. S. Department of Agriculture.

4. ORIFICE FLOW

Definition

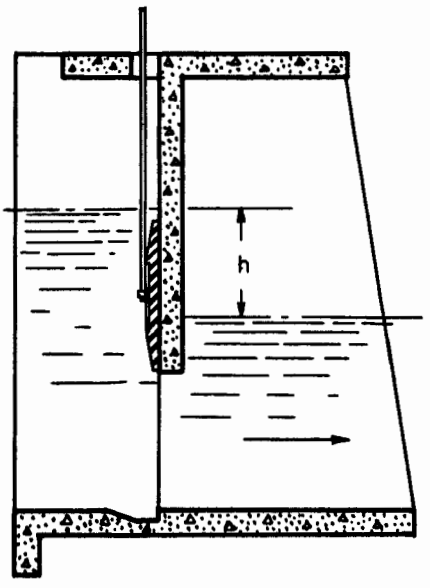
An orifice is an opening with closed perimeter and of regular form through which water flows. If the opening flows only partially full, the orifice becomes a weir. The general formula for discharge through an orifice is:

$$Q = C\,a\,\sqrt{2gh} \quad \text{where,}$$

- Q = discharge c.f.s.
- C = discharge coefficient.
- a = cross-section area of orifice in square feet.
- g = acceleration of gravity, 32.16 feet per second.
- h = head on orifice in feet, where (h) is the head on the center of the orifice for orifices with free discharge and the difference in elevation of water surfaces for submerged orifices.

Flow of Water Through Gates

Gates are used to regulate passage of water through a structure. The discharge is derived from the orifice formula including all losses of head in the coefficient (C). Gate designs differ considerably and have varying degrees of contraction. Figure 16.17 gives values of (C) to be used to meet various conditions applicable to the type of gate shown in Figure 16.16. It will be noted that there is full contraction at the top of the gate.



h = difference in elevation of water surfaces above and below the gate.

Figure 16.16 Submerged Gate

4. ORIFICE FLOW (CONT'D)

Flow of Water Through Gates (cont'd)

COEFFICIENT OF DISCHARGE "C" FOR SUBMERGED GATES

Head in Feet	Width of Opening in Feet		
	2	4	6
0.5	.75	.76	.76
1.0	.73	.74	.75
1.5	.71	.72	.73
2.0	.70	.71	.72
3.0	.68	.69	.70

Taken from King's Handbook of Hydraulics

Figure 16.17

For illustration, assume it is desired to know the discharge of a 2-foot square gate having a difference in elevation of water surface above and below the gate of 1.5 feet, then

$$Q = Ca\sqrt{2gh}$$

C from Figure 16.17 is: .71, a is 4.0 sq. ft., and h is 1.5'

$$Q = .71 \times 4 \sqrt{2 \times 32.2 \times 1.5} = 27.9 \text{ c.f.s.}$$

The values given in Figure 16.17 are the average of the value obtained from the following formulas:

Chattertons Formula: $C = 0.615 + 0.007 \times 2^{5-h}$

Bentons Formula: $C = 0.7201 + .0074W$, where W is the width of opening in feet.

5. PIPE FLOW

Definition

Pipe flow is generally considered to be that flow occurring in a closed conduit and under hydrostatic pressure. Under this condition, the conduit is flowing full. Whenever closed conduits flow partially full, the characteristics of such flow are the same as that for open channel flow.

5. PIPE FLOW (CONT'D)

Pipe Friction

Pressure is required to force water through a pipe due to the friction that is developed by the water coming in contact with the inside surface. Pressure is generally stated in pounds per square inch which is readily converted into feet of head by multiplying the pressure in pounds per square inch by 2.31. The simplest way to create pressure in a water system is to pump the water into an elevated storage tank. The difference in elevation between the water surface in the tank and the outlet is known as the pressure head. For the purpose of simplifying this discussion, pressure will always be stated in terms of equivalent feet of head. The loss of head due to friction or friction head is proportional to the length of pipe, roughness of the pipe, the square of the velocity, and is inversely proportional to the diameter of the pipe. Friction also occurs when water is forced through elbows, valves, or other obstructions in the system. The total head required to produce flow of a given amount of water is the sum of the loss due to friction in the pipe, the loss due to friction in various pipe fittings, and the head required to produce velocity and the inlet loss. The head required to produce velocity is expressed as

$$\frac{v^2}{2g}$$

Values for velocity heads for velocities up to ten feet per second are given in Figure 16.18. Figures 16.20-1 through 9 give the friction loss of various sizes of pipe laid in a straight line when discharging a given quantity of water. To obtain the loss for any other length of pipe, multiply the friction loss by the actual length divided by the appropriate increment of length of the table.

The chart shown in Figure 16.19 gives losses for the various pipe fittings in equivalent lengths of pipe for smooth iron pipe.

Flow of Water in Small Pipes

One of the problems encountered in the field is that of determining pipe sizes and capacities for small pipes such as are used for domestic water supply. These computations involve pipe friction, pressure, length of pipe, number and kind of fittings. The following discussion outlines the major factors to be considered and examples of the use of various tables.

Example: Determine the size pipe required to discharge 10 g.p.m., at the outlet under atmospheric pressure (free discharge) for the installation shown in Figure 16.21.

The total length of the pipeline is 505 feet and contains one globe valve, three 90-degree elbows and two 45-degree elbows. The total effective head (h) is 20 feet. The problem is solved by trial.

VELOCITY HEADS AND ENTRANCE HEADS FOR PIPE IN FEET OF WATER

$h_v = \frac{V^2}{2g}$ $\qquad$ $h_e = K_e \frac{V^2}{2g}$

Velocity in Feet per Second (V)	Velocity Heads	TYPE OF ENTRANCE			
		Inward Projecting $K_e = .78$	Sharp Cornered $K_e = .50$	Slightly Rounded $K_e = .23$	Bell Mouthed $K_e = .04$
0.2	.001	.00078	.0005	.00023	.00004
0.4	.003	.00234	.0015	.00069	.00012
0.6	.006	.00468	.0030	.0014	.00024
0.8	.010	.008	.005	.002	.0004
1.0	.016	.012	.008	.004	.00064
1.2	.022	.017	.011	.005	.0009
1.4	.031	.024	.015	.007	.0012
1.6	.040	.031	.020	.009	.0016
1.8	.050	.039	.025	.011	.002
2.0	.062	.048	.031	.014	.0025
2.2	.075	.058	.037	.017	.003
2.4	.090	.070	.045	.021	.0036
2.6	.105	.082	.053	.024	.004
2.8	.122	.095	.061	.028	.005
3.0	.140	.109	.070	.032	.0056
3.2	.159	.124	.079	.037	.006
3.4	.180	.140	.090	.041	.007
3.6	.202	.156	.101	.046	.008
3.8	.225	.175	.113	.052	.009
4.0	.249	.194	.125	.057	.010
4.2	.274	.214	.137	.063	.011
4.4	.301	.235	.151	.069	.012
4.6	.329	.257	.165	.076	.013
4.8	.358	.279	.179	.082	.014
5.0	.389	.303	.195	.089	.016
5.2	.420	.328	.210	.097	.017
5.4	.453	.353	.227	.104	.018
5.6	.488	.381	.244	.112	.020
5.8	.523	.408	.262	.120	.021
6.0	.560	.437	.280	.129	.022
6.2	.598	.466	.299	.138	.024
6.4	.637	.497	.319	.147	.025
6.6	.677	.528	.339	.156	.026
6.8	.719	.561	.359	.165	.029
7.0	.762	.594	.381	.175	.030
7.2	.806	.629	.403	.185	.032
7.4	.851	.664	.425	.196	.034
7.6	.898	.700	.449	.207	.036
7.8	.946	.738	.473	.218	.038
8.0	.995	.776	.497	.229	.040
8.2	1.045	.815	.522	.240	.042
8.4	1.097	.856	.548	.252	.044
8.6	1.150	.897	.575	.264	.046
8.8	1.204	.939	.602	.277	.048
9.0	1.259	.982	.629	.290	.050
9.2	1.316	1.026	.658	.303	.053
9.4	1.374	1.072	.687	.316	.055
9.6	1.433	1.118	.716	.330	.057
9.8	1.493	1.165	.746	.343	.060
10.0	1.555	1.213	.777	.358	.062

From "Handbook of Water Control" - Hardesty

Figure 16.18

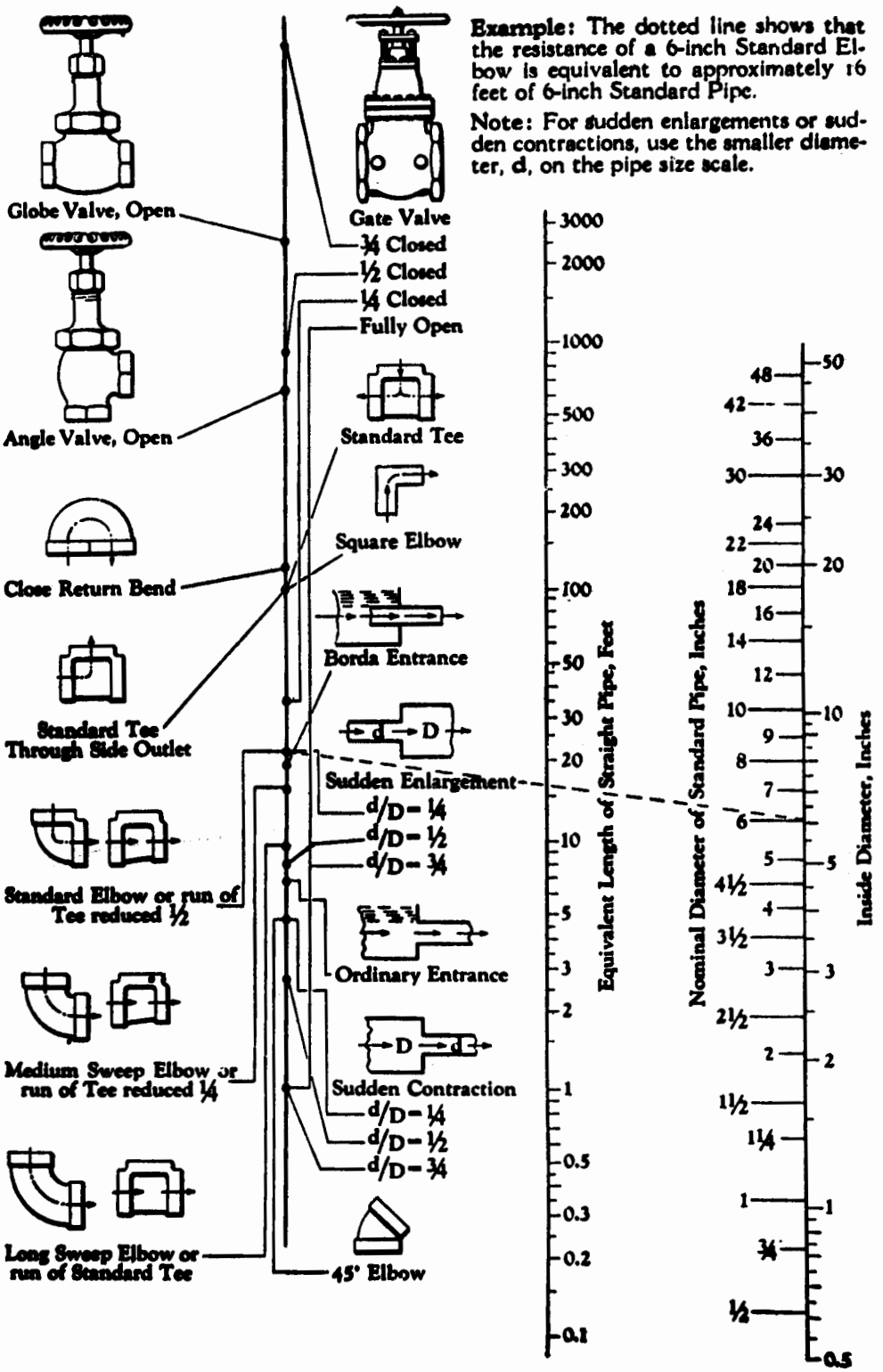


Figure 16.19 Resistance of Valves and Fittings in their Equivalent Length of Straight Pipe, in Feet

FRICTION LOSS IN SMALL DIAMETER PIPE

Gallons of Water Entering Pipe Per Minute	NOMINAL DIAMETER OF PIPE IN INCHES									
	1/4"	3/8"	1/2"	3/4"	1"	1¼"	1½"	2"	2½"	3"
	Friction Loss in Feet for Each 100 Feet of Pipe in Use for 15 Years									
1	27.14	6.06	2.10	.49						
2	99.03	22.22	7.40	1.90						
3			15.80	4.10	1.26					
4			27.00	7.00	2.14	0.57	0.26			
5			41.00	10.50	3.25	0.84	0.39	0.12		
6			54.86	14.15	4.39	1.15	0.52	0.17		
7				18.19	5.63	1.61	0.75	0.23		
8				24.05	7.50	1.93	0.89	0.32		
9				28.58	9.04	2.45	1.18	0.38		
10					11.70	3.05	1.43	0.50	0.17	0.07
12					15.76	4.13	1.93	0.66	0.27	0.10
15					24.05	6.50	3.00	1.00	0.36	0.15
20						11.10	5.20	1.82	0.61	0.25
25						16.60	7.80	2.73	0.92	0.38
30						23.50	11.00	3.84	1.29	0.54

Figure 16.20-1

HEAD LOSS IN FEET PER THOUSAND FEET

Concrete Pipe With Mortar Joints

n = 0.013

Q		D = Diameter of Pipe in Inches									
c.f.s.	g.p.m.	6"	8"	10"	12"	14"	15"	16"	18"	21"	24"
0.5	225	8.0	1.7	0.5	0.2						
0.6	270	11.5	2.5	0.8	0.3	0.1					
0.7	315	15.6	3.4	1.0	0.4	0.2	0.1				
0.8	360	20.4	4.3	1.3	0.5	0.2	0.2	0.1			
0.9	405	25.8	5.6	1.7	0.6	0.3	0.2	0.1			
1.0	449	31.8	6.9	2.1	0.3	0.3	0.2	0.2	0.1		
1.2	539	45.8	9.9	3.0	1.1	0.5	0.3	0.2	0.1		
1.4	628	62.4	13.4	4.1	1.5	0.7	0.5	0.3	0.2	0.1	
1.6	718		17.6	5.3	2.0	0.9	0.6	0.4	0.2	0.1	
1.8	808		22.2	6.8	2.6	1.1	0.8	0.6	0.3	0.1	
2.0	898		27.4	8.3	3.2	1.4	1.0	0.7	0.4	0.2	0.1
2.2	987		33.2	10.1	3.8	1.7	1.2	0.8	0.4	0.2	0.1
2.4	1077		39.5	12.0	4.5	2.0	1.4	1.0	0.5	0.2	0.1
2.6	1167		46.4	14.1	5.3	2.3	1.6	1.1	0.6	0.3	0.1
2.8	1257		53.8	16.4	6.2	2.7	1.9	1.3	0.7	0.3	0.2
3.0	1346			18.8	7.1	3.1	2.2	1.5	0.8	0.4	0.2
3.2	1436			21.4	8.1	3.6	2.5	1.7	0.9	0.4	0.2
3.4	1526			24.1	9.1	4.0	2.8	2.0	1.0	0.5	0.2
3.6	1616			27.0	10.2	4.5	3.1	2.2	1.2	0.5	0.3
3.8	1706			30.1	11.4	5.0	3.5	2.5	1.3	0.6	0.3
4.0	1795			33.3	12.6	5.6	3.8	2.7	1.4	0.6	0.3
4.5	2020			42.3	16.0	7.0	4.9	3.4	1.8	0.8	0.4
5.0	2244			52.2	19.7	8.7	6.0	4.3	2.3	1.0	0.5
5.5	2469				23.9	10.5	7.2	5.1	2.7	1.2	0.6
6.0	2693				28.4	12.5	8.6	6.1	3.3	1.4	0.7
6.5	2917				33.3	14.7	10.1	7.2	3.8	1.7	0.8
7.0	3142				38.7	17.0	11.7	8.3	4.4	1.9	1.0
7.5	3366				44.4	19.5	13.5	9.6	5.1	2.2	1.1
8.0	3591				50.5	22.2	15.3	10.9	5.8	2.5	1.2
8.5	3815					25.1	17.3	12.3	6.5	2.9	1.4
9.0	4039					28.1	19.4	13.8	7.3	3.2	1.6
9.5	4264					31.3	21.6	15.4	8.2	3.6	1.8
10.0	4488					34.7	24.0	17.0	9.1	4.0	2.0
11.0	4937					42.0	29.0	20.6	11.0	4.8	2.4
12.0	5386					50.0	34.5	24.5	13.0	5.7	2.8
13.0	5835						40.5	28.7	15.3	6.7	3.3
14.0	6284						47.0	33.3	17.8	7.8	3.8
16.0	7181						61.3	43.5	23.2	10.2	5.0
18.0	8079							55.1	29.4	12.9	6.3
20.0	8977								36.2	15.9	7.8

Figure 16.20-2

HEAD LOSS IN FEET PER THOUSAND FEET

Concrete Pipe With Concentric Gasket Joints

n = 0.011

Q		D = Diameter of Pipe in Inches									
c.f.s.	g.p.m.	6"	8"	10"	12"	14"	15"	16"	18"	21"	24"
0.5	225	5.7	1.2	0.4	0.1						
0.6	270	8.2	1.8	0.5	0.2	0.1					
0.7	315	11.2	2.4	0.7	0.3	0.1	0.1				
0.8	360	14.6	3.1	1.0	0.4	0.2	0.1				
0.9	405	18.4	4.0	1.2	0.5	0.2	0.1	0.1			
1.0	449	22.8	4.9	1.5	0.6	0.2	0.2	0.1	0.1		
1.2	539	32.8	7.1	2.2	0.8	0.4	0.2	0.2	0.1		
1.4	628	44.7	9.6	2.9	1.1	0.5	0.3	0.2	0.1		
1.6	718	58.3	12.6	3.8	1.4	0.6	0.4	0.3	0.2	0.1	
1.8	808		15.9	4.8	1.8	0.8	0.6	0.4	0.2	0.1	
2.0	898		19.7	6.0	2.3	1.0	0.7	0.5	0.3	0.1	
2.2	987		23.8	7.2	2.7	1.2	0.8	0.6	0.3	0.1	
2.4	1077		28.3	8.6	3.3	1.4	1.0	0.7	0.4	0.2	0.1
2.6	1167		33.2	10.1	3.8	1.7	1.2	0.8	0.4	0.2	0.1
2.8	1257		38.5	11.7	4.4	1.9	1.3	1.0	0.5	0.2	0.1
3.0	1346		44.2	13.5	5.1	2.2	1.5	1.1	0.6	0.3	0.1
3.2	1436		50.3	15.3	5.8	2.5	1.8	1.3	0.7	0.3	0.1
3.4	1526			17.3	6.5	2.9	2.0	1.4	0.7	0.3	0.2
3.6	1616			19.4	7.3	3.2	2.2	1.6	0.8	0.4	0.2
3.8	1706			21.6	8.2	3.6	2.5	1.8	0.9	0.4	0.2
4.0	1795			23.9	9.0	4.0	2.7	2.0	1.0	0.5	0.2
4.5	2020			30.3	11.4	5.0	3.4	2.5	1.3	0.6	0.3
5.0	2244			37.4	14.1	6.2	4.3	3.1	1.6	0.7	0.4
5.5	2469			45.2	17.1	7.5	5.2	3.7	2.0	0.9	0.4
6.0	2693			53.9	20.3	8.9	6.2	4.4	2.3	1.0	0.5
6.5	2917				23.9	10.5	7.2	5.2	2.7	1.2	0.6
7.0	3142				27.7	12.1	8.3	6.0	3.2	1.4	0.7
7.5	3366				31.8	13.9	9.6	6.9	3.6	1.6	0.8
8.0	3591				36.1	15.8	11.0	7.8	4.1	1.8	0.9
8.5	3815				40.8	17.9	12.4	8.8	4.7	2.1	1.0
9.0	4039				45.7	20.1	13.9	9.9	5.2	2.3	1.1
9.5	4264				50.9	22.3	15.5	11.0	5.8	2.6	1.3
10.0	4488					24.8	17.1	12.2	6.5	2.9	1.4
11.0	4937					30.0	20.7	14.8	7.8	3.5	1.7
12.0	5386					35.7	24.7	17.6	9.3	4.1	2.0
13.0	5835					41.8	29.0	20.7	10.9	4.8	2.4
14.0	6284					48.5	33.6	24.0	12.7	5.6	2.7
16.0	7181					63.4	43.9	31.3	16.6	7.3	3.6
18.0	8079						55.5	39.6	21.0	9.2	4.5
20.0	8977							48.9	25.9	11.4	5.6

Figure 16.20-3

HEAD LOSS IN FEET PER THOUSAND FEET

Plastic Pipe

n = 0.009

Q		Nominal Diameter in Inches					
		4	6	8	10	12	15
		Area in Square Feet					
c.f.s.	g.p.m.	.0873	.1963	.3491	.5454	.7854	1.2272
0.1	45	1.3					
0.2	90	5.3					
0.3	135	11.9	1.4	0.3	0.1		
0.4	180	21.2	2.4	0.5	0.2		
0.5	225	33.1	3.8	0.8	0.3	0.1	
0.6	270	47.6	5.5	1.2	0.4	0.1	
0.7	315	64.9	7.5	1.6	0.5	0.2	
0.8	360		9.7	2.1	0.6	0.2	0.1
0.9	405		12.3	2.7	0.8	0.3	0.1
1.0	449		15.2	3.3	1.0	0.4	0.1
1.2	539		21.9	4.7	1.4	0.5	0.2
1.4	628		29.9	6.4	2.0	0.7	0.2
1.6	718		39.0	8.4	2.6	1.0	0.3
1.8	808		49.4	10.7	3.3	1.2	0.4
2.0	898		61.0	13.1	4.0	1.5	0.5
2.2	987			15.9	4.8	1.8	0.6
2.4	1077			19.4	5.8	2.2	0.7
2.6	1167			22.2	6.8	2.6	0.8
2.8	1257			25.8	7.9	3.0	0.9
3.0	1346			29.5	9.0	3.4	1.0
3.2	1436			33.7	10.3	3.9	1.2
3.4	1526			38.0	11.6	4.4	1.3
3.6	1616			42.6	13.0	4.9	1.5
3.8	1706			47.5	14.5	5.5	1.6
4.0	1795			52.6	16.0	6.0	1.8
4.5	2020				20.3	7.7	2.3
5.0	2244				25.1	9.4	2.9
5.5	2469				29.9	11.4	3.5
6.0	2693				36.1	13.6	4.1
6.5	2917				42.4	16.0	4.9
7.0	3142				49.2	18.3	5.6
7.5	3366				56.5	21.3	6.5
8.0	3591					23.7	7.4
8.5	3815					27.3	8.3
9.0	4039					30.6	9.3
9.5	4264					34.1	10.4
10.0	4488					37.8	11.5
11.0	4937					45.7	13.9
12.0	5386					54.5	16.6
13.0	5835						19.4
14.0	6284						22.6
16.0	7181						29.4
18.0	8079						37.3
20.0	8977						46.0

Figure 16.20-4

HEAD LOSS IN FEET PER THOUSAND FEET
Smooth Interior Corrugated Metal Pipe
n = 0.010

Q		Nominal Diameter in Inches						
		8	10	12	15	18	21	24
		Area in Square Feet						
c.f.s.	g.p.m.	.328	.519	.753	1.187	1.718	2.348	3.076
0.3	135	0.4	0.1					
0.4	180	0.8	0.2					
0.5	225	1.2	0.3	0.1				
0.6	270	1.7	0.5	0.2				
0.7	315	2.3	0.7	0.3				
0.8	360	3.1	0.9	0.3	0.1			
0.9	405	3.9	1.1	0.4	0.1			
1.0	449	4.8	1.4	0.5	0.2			
1.2	539	6.9	2.0	0.7	0.2	0.1		
1.4	628	9.4	2.8	1.0	0.3	0.1		
1.6	718	12.3	3.6	1.3	0.4	0.1		
1.8	808	15.6	4.6	1.7	0.5	0.2	0.1	
2.0	898	19.2	5.6	2.1	0.6	0.2	0.1	
2.2	987	23.2	6.8	2.5	0.7	0.3	0.1	
2.4	1077	27.6	8.1	3.0	0.9	0.3	0.1	
2.6	1167	32.4	9.5	3.5	1.0	0.4	0.2	0.1
2.8	1257	37.6	11.0	4.1	1.2	0.5	0.2	0.1
3.0	1346	43.2	12.7	4.7	1.4	0.5	0.2	0.1
3.2	1436	49.1	14.4	5.3	1.6	0.6	0.3	0.1
3.4	1526	55.5	16.3	6.0	1.8	0.7	0.3	0.1
3.6	1616		18.3	6.8	2.0	0.8	0.3	0.2
3.8	1706		20.3	7.5	2.2	0.8	0.4	0.2
4.0	1795		22.6	8.3	2.5	0.9	0.4	0.2
4.5	2020		28.5	10.6	3.1	1.2	0.5	0.2
5.0	2244		35.2	13.1	3.9	1.4	0.6	0.3
5.5	2469		42.6	15.8	4.7	1.7	0.8	0.4
6.0	2693		50.7	18.8	5.6	2.1	0.9	0.4
6.5	2917			22.0	6.6	2.4	1.1	0.5
7.0	3142			25.6	7.6	2.8	1.2	0.6
7.5	3366			39.4	8.7	3.3	1.4	0.7
8.0	3591			33.5	9.9	3.7	1.6	0.8
8.5	3815			37.7	11.2	4.2	1.8	0.9
9.0	4039			42.3	12.6	4.7	2.0	1.0
9.5	4264			47.1	14.0	5.2	2.3	1.1
10.0	4488			52.2	15.5	5.8	2.5	1.2
11.0	4937				18.8	7.0	3.0	1.5
12.0	5386				22.3	8.3	3.6	1.8
13.0	5835				26.2	9.8	4.3	2.1
14.0	6284				30.4	11.3	4.9	2.4
16.0	7181				39.7	14.8	6.4	3.1
18.0	8079				50.2	18.8	8.1	4.0
20.0	8977					23.5	10.1	4.9

Figure 16.20-5

HEAD LOSS IN FEET PER THOUSAND FEET
Inside Lined Welded Steel Pipe
n = 0.010

Q		Nominal Diameter in Inches												
		4			6			8			10		12	
		Gauge			Gauge			Gauge			Gauge		Gauge	
		16	14	12	16	14	12	16	14	12	14	12	14	12
		Area in Square Feet												
cfs	gpm	.082	.081	.078	.189	.187	.183	.339	.336	.331	.529	.522	.766	.758
0.1	45	1.9	2.0	2.2										
0.2	90	7.7	8.0	8.8										
0.3	135	17.4	17.9	19.8										
0.4	180	30.9	32.0	35.0										
0.5	225	48.2	49.9	55.0	5.2	5.3	5.7	1.1	1.1	1.2	0.3	0.3	0.1	0.1
0.6	270	69.4	72.0	79.2	7.5	7.7	8.2	1.6	1.6	1.7	0.5	0.5	0.2	0.2
0.7	315				10.2	10.5	11.2	2.1	2.2	2.3	0.7	0.7	0.2	0.3
0.8	360				13.3	13.7	14.5	2.8	2.9	3.0	0.9	0.9	0.3	0.3
0.9	405				16.9	17.3	18.4	3.5	3.6	3.8	1.1	1.1	0.4	0.4
1.0	449				20.8	21.5	22.7	4.4	4.5	4.7	1.3	1.4	0.5	0.5
1.2	539				30.0	30.9	32.8	6.3	6.5	6.8	1.9	2.0	0.7	0.7
1.4	628				40.9	42.0	44.5	8.6	8.8	9.2	2.6	2.7	1.0	1.0
1.6	718				53.4	54.9	58.1	11.2	11.5	12.0	3.4	3.6	1.3	1.3
1.8	808							14.2	14.6	15.2	4.3	4.5	1.6	1.7
2.0	898							17.6	18.0	18.7	5.4	5.5	2.0	2.1
2.2	987							21.2	21.8	22.7	6.5	6.7	2.4	2.5
2.4	1077							25.3	25.9	27.0	7.7	8.0	2.9	3.0
2.6	1167							29.7	30.4	31.6	9.0	9.6	3.4	3.5
2.8	1257							34.4	35.2	36.7	10.5	10.9	3.9	4.0
3.0	1346							39.5	40.5	42.1	12.0	12.5	4.5	4.6
3.2	1436							44.9	46.0	47.9	13.7	14.2	5.1	5.3
3.4	1526							50.4	51.8	54.4	15.5	16.0	5.8	5.9
3.6	1616										17.4	18.0	6.5	6.7
3.8	1706										19.3	20.0	7.2	7.4
4.0	1795										21.4	22.2	8.0	8.2
4.5	2020										27.1	28.1	10.1	10.4
5.0	2244										33.5	34.7	12.5	12.8
5.5	2469										40.5	42.0	15.1	15.5
6.0	2693										48.2	49.9	18.0	18.5
6.5	2917										56.6	58.6	21.1	21.7
7.0	3142												24.5	25.1
7.5	3366												28.1	28.8
8.0	3591												31.9	32.8
8.5	3815												36.1	37.1
9.0	4039												40.4	41.6
9.5	4264												45.0	46.3
10.0	4488												49.9	51.4
11.0	4937												60.4	62.1
12.0														
13.0														
14.0														
16.0														
18.0														
20.0														

Figure 16.20-6

HEAD LOSS IN FEET PER THOUSAND FEET
Inside Lined Welded Steel Pipe
n = 0.010

Q		Nominal Diameter in Inches											
		14		16		18		20		22		24	
		Gauge		Gauge		Gauge		Gauge		Gauge		Gauge	
		12	10	12	10	12	10	10	7	10	7	10	7
		Area in Square Feet											
cfs	gpm	1.04	1.03	1.36	1.35	1.73	1.72	2.12	2.10	2.58	2.55	3.07	3.05
0.3	135												
0.4	180												
0.5	225	0.1	0.1										
0.6	270	0.1	0.1										
0.7	315	0.1	0.1										
0.8	360	0.1	0.1	0.1	0.1								
0.9	405	0.2	0.2	0.1	0.1								
1.0	449	0.2	0.2	0.1	0.1	0.1	0.1						
1.2	539	0.3	0.3	0.2	0.2	0.1	0.1						
1.4	628	0.4	0.4	0.2	0.2	0.1	0.1	0.1	0.1				
1.6	718	0.6	0.6	0.3	0.3	0.1	0.1	0.1	0.1				
1.8	808	0.7	0.7	0.3	0.4	0.2	0.2	0.1	0.1	0.1	0.1		
2.0	898	0.9	0.9	0.4	0.4	0.2	0.2	0.1	0.1	0.1	0.1		
2.2	987	1.1	1.1	0.5	0.5	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1
2.4	1077	1.3	1.3	0.6	0.6	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1
2.6	1167	1.5	1.5	0.7	0.7	0.4	0.4	0.2	0.2	0.1	0.1	0.1	0.1
2.8	1257	1.7	1.8	0.8	0.9	0.4	0.5	0.3	0.3	0.2	0.2	0.1	0.1
3.0	1346	2.0	2.0	1.0	1.0	0.5	0.5	0.3	0.3	0.2	0.2	0.1	0.1
3.2	1436	2.3	2.3	1.1	1.1	0.6	0.6	0.3	0.3	0.2	0.2	0.1	0.1
3.4	1526	2.6	2.6	1.2	1.3	0.7	0.7	0.4	0.4	0.2	0.2	0.1	0.1
3.6	1616	2.9	2.9	1.4	1.4	0.7	0.7	0.4	0.4	0.3	0.3	0.2	0.2
3.8	1706	3.2	3.3	1.6	1.6	0.8	0.8	0.5	0.5	0.3	0.3	0.2	0.2
4.0	1795	3.5	3.6	1.7	1.8	0.9	0.9	0.5	0.5	0.3	0.3	0.2	0.2
4.5	2020	4.5	4.6	2.2	2.2	1.1	1.2	0.7	0.7	0.4	0.4	0.3	0.3
5.0	2244	5.5	5.7	2.7	2.7	1.4	1.4	0.8	0.9	0.5	0.5	0.3	0.3
5.5	2469	6.7	6.9	3.3	3.3	1.7	1.7	1.0	1.0	0.6	0.6	0.4	0.4
6.0	2693	7.9	8.2	3.9	4.0	2.0	2.1	1.2	1.2	0.7	0.7	0.4	0.5
6.5	2917	9.3	9.6	4.6	4.6	2.4	2.4	1.4	1.4	0.8	0.9	0.5	0.5
7.0	3142	10.8	11.1	5.3	5.4	2.8	2.8	1.6	1.7	1.0	1.0	0.6	0.7
7.5	3366	12.4	12.7	6.1	6.2	3.2	3.2	1.9	1.9	1.1	1.1	0.7	0.7
8.0	3591	14.1	14.5	6.9	7.1	3.6	3.7	2.1	2.2	1.3	1.3	0.8	0.8
8.5	3815	15.9	16.4	7.8	8.0	4.1	4.2	2.4	2.5	1.4	1.5	0.9	0.9
9.0	4039	17.9	18.4	8.8	8.9	4.6	4.7	2.7	2.8	1.6	1.6	1.0	1.0
10.0	4488	22.1	22.7	10.8	11.0	5.7	5.8	3.3	3.4	2.0	2.0	1.2	1.2
11.0	4937	26.7	27.4	13.1	13.3	6.9	7.0	4.0	4.1	2.4	2.4	1.5	1.5
12.0	5386	31.8	32.6	15.5	15.9	8.2	8.3	4.8	4.9	2.8	2.9	1.8	1.8
13.0	5835	37.3	38.3	18.3	18.6	9.6	9.8	5.6	5.7	3.3	3.4	2.0	2.1
14.0	6284	43.2	44.4	21.2	21.6	11.1	11.3	6.5	6.7	3.8	4.0	2.4	2.4
16.0	7181	50.9	56.5	27.6	28.2	14.6	14.8	8.5	8.7	5.0	5.2	3.1	3.2
18.0	8079			35.0	35.7	18.4	18.7	10.7	11.0	6.3	6.5	4.0	4.1
20.0	8977			43.2	44.0	22.7	23.7	13.2	13.6	7.8	8.1	4.9	5.0

Figure 16.20-7

HEAD LOSS IN FEET PER THOUSAND FEET
Unlined Welded Steel Pipe
n = 0.012

Q		Nominal Diameter in Inches												
		4			6			8			10		12	
		Gauge			Gauge			Gauge			Gauge		Gauge	
		16	14	12	16	14	12	16	14	12	14	12	14	12
		Area in Square Feet												
cfs	gpm	.082	.081	.078	.189	.187	.183	.339	.336	.331	.529	.522	.766	.758
0.1	45	2.8	2.9	3.2										
0.2	90	11.1	11.5	12.6										
0.3	135	25.0	25.8	28.6										
0.4	180	44.5	46.1	50.8										
0.5	225	69.5	71.9	79.2	7.5	7.7	8.2	1.6	1.6	1.7	0.5	0.5	0.2	0.2
0.6	270				10.8	11.1	11.8	2.3	2.3	2.4	0.7	0.7	0.3	0.3
0.7	315				14.7	15.1	16.1	3.1	3.2	3.3	0.9	1.0	0.3	0.4
0.8	360				19.2	19.8	20.9	4.0	4.1	4.3	1.2	1.3	0.5	0.5
0.9	405				24.3	25.0	26.5	5.1	5.2	5.5	1.6	1.6	0.6	0.6
1.0	449				30.0	31.0	32.7	6.3	6.5	6.7	1.9	2.0	0.7	0.7
1.2	539				43.2	44.5	47.2	9.1	9.3	9.7	2.8	2.9	1.0	1.1
1.4	638				58.9	60.5	64.1	12.4	12.7	13.2	3.8	3.9	1.4	1.5
1.6	718							16.2	16.6	17.2	4.9	5.1	1.8	1.9
1.8	808							20.5	21.0	21.9	6.2	6.5	2.3	2.4
2.0	898							25.3	25.9	26.9	7.7	8.0	2.9	3.0
2.2	987							30.6	31.3	32.6	9.3	9.7	3.5	3.6
2.4	1077							36.4	37.3	38.8	11.1	11.5	4.1	4.3
2.6	1167							42.7	43.8	45.5	13.0	13.9	4.8	5.0
2.8	1257							49.5	50.7	52.8	15.1	15.6	5.6	5.8
3.0	1346							56.9	58.3	60.6	17.3	18.0	6.5	6.7
3.2	1436										19.8	20.5	7.4	7.6
3.4	1526										22.3	23.1	8.3	8.5
3.6	1616										25.0	25.9	9.3	9.6
3.8	1706										27.8	28.9	10.4	10.7
4.0	1795										30.8	32.0	11.5	11.8
4.5	2020										39.1	40.5	14.5	15.0
5.0	2244										48.2	50.0	18.0	18.5
5.5	2469										58.4	60.5	21.7	22.4
6.0	2693												25.9	26.6
6.5	2917												30.4	31.3
7.0	3142												35.2	36.2
7.5	3366												40.4	41.5
8.0	3591												46.0	47.3
8.5	3815												52.0	55.3
9.0	4039													
9.5	4264													
10.0	4488													
11.0	4937													
12.0	5386													
13.0	5835													
14.0	6284													
16.0	7181													
18.0	8079													
20.0	8977													

Figure 16.20-8

HEAD LOSS IN FEET PER THOUSAND FEET
Unlined Welded Steel Pipe
n = 0.012

Q		Nominal Diameter in Inches											
		14		16		18		20		22		24	
		Gauge		Gauge		Gauge		Gauge		Gauge		Gauge	
		12	10	12	10	12	10	12	10	12	10	12	10
		Area in Square Feet											
cfs	gpm	1.04	1.03	1.36	1.35	1.73	1.72	2.12	2.10	2.58	2.55	3.07	3.05
0.5	225	0.1	0.1										
0.6	270	0.1	0.1										
0.7	315	0.2	0.2										
0.8	360	0.2	0.2	0.1	0.1								
0.9	405	0.3	0.3	0.2	0.2								
1.0	449	0.3	0.3	0.2	0.2	0.1	0.1						
1.2	539	0.5	0.5	0.3	0.3	0.1	0.1						
1.4	628	0.6	0.6	0.4	0.4	0.2	0.2	0.1	0.1				
1.6	718	0.8	0.8	0.5	0.5	0.2	0.2	0.1	0.1				
1.8	808	1.0	1.1	0.6	0.6	0.3	0.3	0.2	0.2	0.1	0.1		
2.0	898	1.3	1.3	0.8	0.8	0.3	0.3	0.2	0.2	0.1	0.1	0.1	0.1
2.2	987	1.5	1.6	0.9	0.9	0.4	0.4	0.2	0.2	0.1	0.1	0.1	0.1
2.4	1077	1.8	1.8	1.0	1.1	0.5	0.5	0.3	0.3	0.2	0.2	0.1	0.1
2.6	1167	2.1	2.2	1.2	1.2	0.6	0.6	0.3	0.3	0.2	0.2	0.1	0.1
2.8	1257	2.5	2.6	1.4	1.4	0.6	0.7	0.4	0.4	0.2	0.2	0.1	0.1
3.0	1346	2.9	2.9	1.6	1.6	0.7	0.7	0.4	0.4	0.3	0.3	0.2	0.2
3.2	1436	3.3	3.3	1.8	1.8	0.8	0.9	0.5	0.5	0.3	0.3	0.2	0.2
3.4	1526	3.7	3.8	2.0	2.0	0.9	1.0	0.5	0.6	0.3	0.3	0.2	0.2
3.6	1616	4.1	4.2	2.2	2.3	1.1	1.1	0.6	0.6	0.4	0.4	0.2	0.2
3.8	1706	4.6	4.7	2.5	2.5	1.2	1.2	0.7	0.7	0.4	0.4	0.3	0.3
4.0	1795	5.1	5.2	3.2	3.2	1.3	1.3	0.8	0.8	0.5	0.5	0.3	0.3
4.5	2020	6.4	6.6	3.9	4.0	1.7	1.7	1.0	1.0	0.6	0.6	0.4	0.4
5.0	2244	8.0	8.1	4.7	4.8	2.0	2.1	1.2	1.2	0.7	0.7	0.4	0.5
5.5	2469	9.6	9.9	5.6	5.7	2.5	2.5	1.4	1.5	0.9	0.9	0.5	0.5
6.0	2693	11.4	11.8	6.6	6.7	2.9	3.0	1.7	1.8	1.0	1.0	0.6	0.7
6.5	2917	13.4	13.8	7.6	7.8	3.5	3.5	2.0	2.1	1.2	1.2	0.8	0.8
7.0	3142	15.6	16.0	8.7	8.9	4.0	4.1	2.3	2.4	1.4	1.4	0.9	1.0
7.5	3366	17.9	18.3	9.9	10.2	4.6	4.7	2.7	2.7	1.6	1.6	1.0	1.0
8.0	3591	20.3	20.9	11.2	11.5	5.2	5.3	3.0	3.1	1.8	1.9	1.1	1.2
8.5	3815	22.9	23.6	12.6	12.9	5.9	6.0	3.4	3.5	2.0	2.1	1.3	1.3
9.0	4039	25.7	26.4	14.1	14.3	6.6	6.7	3.9	4.0	2.3	2.4	1.4	1.5
9.5	4264	28.6	29.4	15.5	15.7	7.4	7.5	4.3	4.4	2.5	2.6	1.6	1.6
10.0	4488	31.8	32.6	18.8	19.2	8.2	8.3	4.8	4.9	2.8	2.9	1.8	1.8
11.0	4937	38.5	39.5	22.4	22.8	9.9	10.1	5.8	5.9	3.4	3.5	2.1	2.2
12.0	5386	45.8	46.9	26.3	26.8	11.8	12.0	6.9	7.0	4.1	4.2	2.6	2.6
13.0	5835	53.7	55.7	30.5	31.1	13.8	14.0	8.0	8.3	4.8	4.9	3.0	3.0
14.0	6284			39.8	40.6	16.0	16.3	9.3	9.6	5.5	5.7	3.5	3.5
16.0	7181			50.4	51.4	21.0	21.3	12.2	12.5	7.2	7.4	4.5	4.6
18.0	8079					26.5	26.9	15.4	15.8	9.1	9.4	5.7	5.8
20.0	8979					32.7	33.4	19.0	19.5	11.3	11.6	7.1	7.2

Figure 16.20-9

5. PIPE FLOW (CONT'D)

Flow of Water in Small Pipes (cont'd)

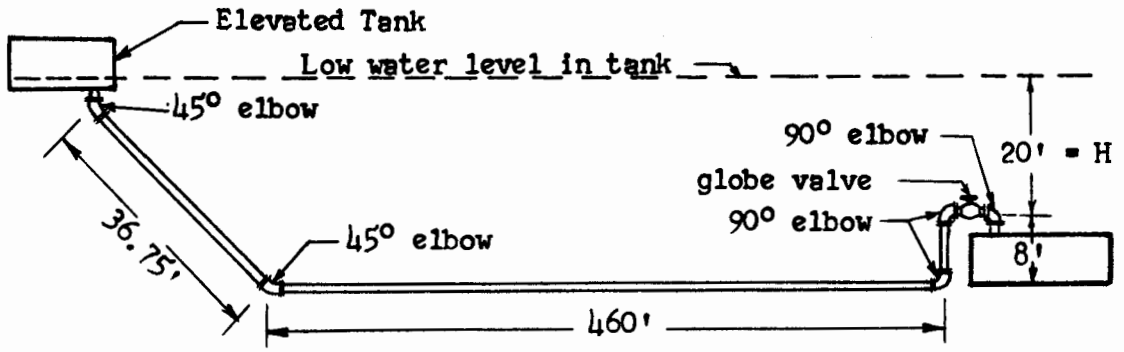


Figure 16.21 Typical Small Pipe Installation

Assume 1¼-inch diameter steel pipe. The friction loss under a discharge of 10 g.p.m., is 3.05 feet per 100 feet of pipe from Figure 16.20-1. The loss of head incurred in the fittings based on the equivalent length of pipe from Figure 16.19 is:

3 - 1¼-inch diameter 90-degree elbows @ 3.75 ft.	=	11.25
2 - 1¼-inch diameter 45-degree elbows @ 1.72 ft.	=	3.44
1 - Globe valve	=	36.00
		50.69

The total friction head loss in the system will be:

$$\frac{505 + 50.7}{100} \times 3.05 = 16.9$$

This computation shows that a difference in elevation of 16.9 feet would produce a flow of 10 g.p.m. Actually, the difference is 20 feet, which means that the water, as it discharges is under a head of 3.1 feet, which is on the safe side.

Flow Through Outlets or Culverts

The quantity of water that will pass through an outlet pipe depends on the total head or pressure, the size of the pipe, the length of the pipe, the materials of which the pipe is made, entrance and outlet conditions, and the presence of sharp bends, sudden enlargements, sudden contractions, or other conditions that tend to disturb uniform flow. Under these conditions, the capacity of the pipe may be figured as that of a short tube, having both ends submerged, using the orifice formula $Q = C_a \sqrt{2gh}$, including all losses of head in the coefficient of discharge (C). The formula applied will permit accurate estimates of flow to be rapidly made. To obtain the maximum discharge, the intake must be submerged to a depth equal at least to the sum of the velocity head and loss of head at entrance. The discharge is entirely independent of the slope of the tube. It depends only on (h), the difference in elevation of water surface at intake and

TABLE 15

COEFFICIENTS OF DISCHARGE "C" FOR CULVERTS *

Corrugated Metal Pipe, Square-Cornered Entrance

Length "L"	Diameter of Pipe "d"							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
10	.53	.67	.74	.77	.78	.79	.80	.80
20	.41	.55	.63	.68	.71	.73	.74	.75
30	.34	.48	.56	.62	.65	.68	.70	.71
40	.30	.43	.51	.57	.61	.64	.66	.68
50	.27	.39	.47	.53	.57	.61	.63	.65
60	.25	.36	.44	.50	.54	.58	.60	.62
70	.23	.34	.42	.47	.52	.55	.58	.60
80	.22	.32	.40	.45	.49	.53	.56	.58
90	.21	.31	.38	.43	.47	.51	.54	.56
100	.20	.29	.36	.41	.46	.49	.52	.54

Concrete Pipe, Square-Cornered Entrance

Length "L"	Diameter of Pipe "d"							
	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
10	.74	.80	.81	.80	.80	.79	.78	.77
20	.64	.74	.77	.78	.78	.77	.77	.76
30	.58	.69	.73	.75	.76	.76	.76	.75
40	.53	.65	.70	.73	.74	.74	.74	.74
50	.49	.62	.68	.71	.72	.73	.73	.73
60	.46	.59	.65	.69	.71	.72	.72	.72
70	.43	.57	.63	.67	.69	.70	.71	.71
80	.41	.54	.61	.65	.68	.69	.70	.70
90	.39	.52	.60	.64	.66	.68	.69	.70
100	.37	.51	.58	.62	.65	.67	.68	.69

Concrete-Box Culvert, Square-Cornered Entrance

Length "L"	Hydraulic Radius "r"							
	0.2	0.3	0.4	0.5	0.6	0.8	1.0	1.2
10	.79	.82	.83	.84	.84	.84	.83	.83
20	.72	.77	.79	.81	.81	.82	.82	.82
30	.67	.73	.76	.78	.79	.80	.81	.81
40	.62	.69	.73	.76	.77	.79	.80	.80
50	.58	.66	.71	.73	.75	.77	.78	.79
60	.55	.63	.68	.71	.73	.76	.77	.78
70	.53	.61	.66	.69	.72	.75	.76	.77
80	.50	.59	.64	.68	.70	.74	.75	.76
90	.48	.57	.62	.66	.69	.72	.74	.76
100	.47	.55	.61	.65	.67	.71	.74	.75

From "Flow of Water Through Culverts" - Iowa Bulletin #1

Figure 16.22

5. PIPE FLOW (CONT'D)

Flow Through Outlets or Culverts (cont'd)

outlet. Figure 16.22 gives values of the discharge coefficient (C) for the various diameters and lengths of culverts. Inasmuch as the experiments from which the above coefficients were derived include only lengths of 24 to 36 feet, it would appear best for long culverts to use the (C) for a length of 25 to 50 feet and compute the head lost in the remainder of the conduit by an open channel or pipe formula. The (h) to be used is then the difference in elevation of water surfaces at entrance and outlet minus this computed loss of head. In selecting values of (C) for intermediate size culverts, discharge coefficients may be interpolated from the tables.

An example showing the steps followed in the solution of a typical problem follows:

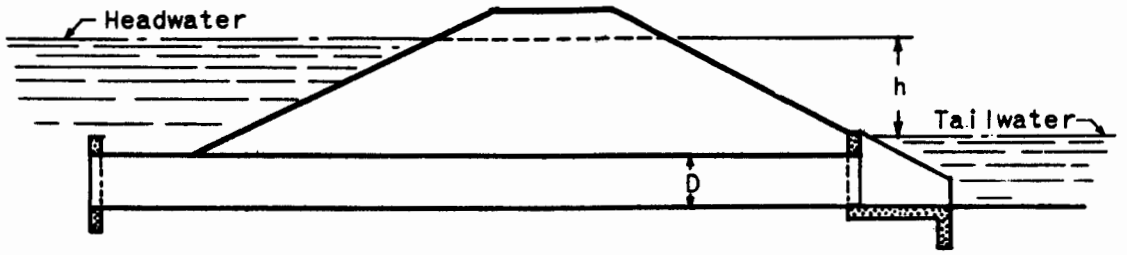


Figure 16.23

Determine the diameter of corrugated metal culvert pipe in Figure 16.23 required when subjected to the following conditions:

Rate of flow	= 13 c.f.s.
Length	= 50 feet
Maximum head (h), (difference in elevation of water surface upstream and downstream)	= 4.0 feet

Since the solution of this problem involves the trial method, a value of (C) of 0.50 will be assumed.

From the formula $Q = CA\sqrt{2gh}$, $A = \dfrac{Q}{C\sqrt{2gh}}$;

$$A = \frac{13}{0.50\ \sqrt{2 \times 32.16 \times 4}} = \frac{13}{0.50 \times 16.04} = 1.62 \text{ sq. ft.}$$

Area of circular section $= 3.14 \times \dfrac{d^2}{4}$, $\therefore d^2 = \dfrac{4A}{3.14}$

$$d^2 = \frac{4 \times 1.62}{3.14} = 2.07; \qquad d = 1.44 \text{ feet.}$$

SMOOTH PIPE CULVERTS - Free Outlet
With Water Surface at Inlet Same Elevation as Top of Pipe, and Outlet Unsubmerged
Values Are in Cubic Feet Per Second

Slope in Per Cent	DIAMETER OF PIPE, IN INCHES																				
	8	10	12	15	18	21	24	30	36	42	48	54	60	66	72	78	84	90	96	108	120
.1	0.4	.08	1.2	2.1	3.5	5.4	7.5	14	22	34	50	70	90	115	145	180	213	250	310	430	550
.2	0.6	1.2	1.8	3.2	5.0	7.6	10.8	19	31	47	67	95	125	158	197	242	290	350	415	465	730
.3	0.7	1.4	2.2	3.8	5.9	8.9	12.8	23	37	54	77	104	137	178	220	268	325	390	455	615	805
.4	0.8	1.4	2.3	4.1	6.5	9.7	13.9	24	39	58	**83**	108	142	183	227	**280**	**330**	**400**	**470**	**630**	**810**
.5	0.8	1.5	2.4	4.4	6.8	10	14.4	25	**40**	**59**	83	**110**	145	185	**230**	280	330	400	470	630	810
.6	**0.9**	**1.8**	2.5	4.5	7.0	10	**15**	**26**	40	59	83	110	**150**	**190**	230	280	330	400	470	630	810
.8	0.9	1.6	**2.6**	**4.8**	**7.1**	**11**	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
1.0	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
1.2	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
1.4	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
1.6	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
1.8	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.0	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.2	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.4	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810

Figure 16.24

CORRUGATED PIPE CULVERTS - Free Outlet
With Water Surface at Inlet Same Elevation as Top of Pipe, and Outlet Unsubmerged
Values Are in Cubic Feet Per Second

Slope in Per Cent	DIAMETER OF PIPE, IN INCHES																				
	8	10	12	15	18	21	24	30	36	42	48	54	60	66	72	78	84	90	96	108	120
.1	0.2	0.4	0.6	1.3	2.1	3.3	4.7	8	12	20	25	36	47	67	85	110	130	160	190	270	330
.2	0.3	0.6	1.0	2.0	3.1	4.7	6.8	12	19	30	42	57	77	100	130	160	190	230	270	380	500
.3	0.4	0.8	1.3	2.4	3.9	5.9	8.3	15	25	37	53	72	97	120	150	190	230	280	330	450	600
.4	0.5	0.9	1.5	2.8	4.4	6.8	9.5	17	28	42	62	83	110	140	180	220	270	320	380	510	670
.5	0.6	1.0	1.7	3.0	4.9	7.5	10.	19	31	46	68	90	120	150	190	240	290	340	410	560	730
.6	0.6	1.1	1.9	3.3	5.4	8.1	11.	21	33	50	72	97	130	160	210	250	300	360	430	580	770
.8	0.8	1.2	2.1	3.7	6.1	9.0	13	23	37	55	77	100	140	180	220	270	320	390	460	620	**810**
1.0	0.8	1.4	2.3	4.0	6.5	9.6	14	24	39	57	80	**110**	140	180	**230**	**280**	**330**	**400**	**470**	**630**	810
1.2	0.8	1.5	2.4	4.3	6.8	10.	14	25	**40**	**59**	82	110	**150**	**180**	230	280	330	400	470	630	810
1.4	**0.9**	**1.6**	2.5	4.4	7.0	10	**15**	25	40	59	**83**	110	150	190	230	280	330	400	470	630	810
1.6	0.9	1.6	**2.6**	4.5	**7.1**	10	15	**26**	40	59	83	110	150	190	230	280	330	400	470	630	810
1.8	0.9	1.6	2.6	**4.6**	7.1	**11**	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.0	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.2	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810
2.4	0.9	1.6	2.6	4.6	7.1	11	15	26	40	59	83	110	150	190	230	280	330	400	470	630	810

Note: The values in bold face type indicate discharge at the approximate "critical slope," beyond which the discharge remains constant for any given size culvert.

The "stairs" of heavy horizontal lines beginning at the upper left and reading downward and to the right indicate approximate velocities of 2, 4, 6, 8 and 10 feet per second.

Figure 16.25

Taken from "Handbook of Water Control - Hardesty Co.

CAPACITY OF CORRUGATED METAL PIPE
CASE II - SUBMERGED OUTLET
CULVERT FLOWING FULL - STRAIGHT ENDWALL ENTRANCE
CULVERT LENGTH 30.6 FEET
Values are in Cubic Feet Per Second

Head on Pipe in Feet	12 inch	*15 inch	18 inch	*21 inch	24 inch	30 inch	*36 inch	*42 inch	*48 inch
.01	0.31	.52	.79	1.13	1.54	2.57	3.92	5.60	7.62
.02	.44	.73	1.12	1.60	2.17	3.64	5.55	7.92	10.8
.03	.54	.90	1.37	1.96	2.66	4.46	6.79	9.70	13.2
.04	.62	1.04	1.58	2.26	3.07	5.15	7.84	11.2	15.2
.05	.69	1.16	1.77	2.52	3.44	5.76	8.77	12.5	17.0
.06	.76	1.27	1.94	2.77	3.76	6.30	9.61	13.7	18.7
.07	.82	1.37	2.09	2.99	4.07	6.82	10.4	14.8	20.2
.08	.88	1.47	2.24	3.19	4.35	7.28	11.1	15.8	21.5
.09	.93	1.56	2.38	3.39	4.61	7.72	11.8	16.8	22.9
.1	.98	1.64	2.50	3.57	4.86	8.14	12.4	17.7	24.1
.2	1.39	2.32	3.54	5.05	6.87	11.5	17.5	25.0	34.1
.3	1.70	2.84	4.33	6.18	8.42	14.1	21.5	30.7	41.8
.4	1.96	3.28	5.00	7.14	9.72	16.3	24.8	35.4	48.2
.5	2.19	3.67	5.59	7.98	10.9	18.2	27.7	39.6	53.9
.6	2.40	4.02	6.13	8.75	11.9	19.9	30.4	43.4	59.1
.7	2.59	4.34	6.62	9.45	12.9	21.5	32.8	46.9	63.8
.8	2.77	4.64	7.07	10.1	13.8	23.0	35.1	50.1	68.2
.9	2.94	4.92	7.51	10.7	14.6	24.4	37.2	53.1	72.3
1.0	3.10	5.19	7.91	11.3	15.4	25.7	39.2	56.0	76.2
1.2	3.40	5.69	8.66	12.4	16.8	28.2	43.0	61.3	83.5
1.4	3.67	6.14	9.36	13.4	18.2	30.5	46.4	66.3	90.2
1.6	3.92	6.57	10.00	14.3	19.4	32.6	49.6	70.8	96.4
1.8	4.16	6.96	10.60	15.2	20.6	34.5	52.6	75.1	102.0
2.0	4.38	7.34	11.20	16.0	21.7	36.4	55.5	79.2	108
2.2	4.60	7.70	11.74	16.8	22.8	38.2	58.2	83.1	113
2.4	4.80	8.04	12.25	17.5	23.8	39.9	60.8	86.8	118
2.6	5.00	8.37	12.81	18.2	24.8	41.7	63.0	90.3	123
2.8	5.19	8.69	13.24	18.9	25.7	43.1	65.6	93.7	128
3.0	5.37	8.99	13.70	19.6	26.6	44.6	67.9	97.0	132
3.2	5.55	9.29	14.26	20.2	27.5	46.1	70.2	100.2	136
3.4	5.72	9.57	14.60	20.8	28.4	47.5	72.3	103.5	141
3.5	5.80	9.71	14.80	21.1	28.8	48.2	73.4	105.0	143

NOTE—This table is based on the formula $Q = 3.10\ D^{2.31}\ H^{0.50}$ for corrugated pipe in which Q = discharge in cubic feet per sec. D = diameter of pipe in feet and H = head on pipe in feet = difference in elevation of water surface at inlet and outlet ends.

*No experiments made on these sizes—Quantity computed by formula.

This capacity table is compiled from figures obtained through a series of tests made by the Bureau of Public Roads at the Hydraulic Testing Plant of the University of Iowa. Note that capacities are for 30.6 ft. lengths of pipe.

The figures in bold face type are for velocities of approx. 2, 4 and 6 ft. per second, reading downwards.

Taken from "Handbook of Water Control" - Hardesty Co.

Figure 16.26

5. PIPE FLOW (CONT'D)

Flow Through Outlets or Culverts (cont'd)

Try 1.5-foot or 18-inch culvert.

Checking: C from Figure 16.22 = .47

$$Q = CA\sqrt{2gh} = .47 \times 3.14 \frac{(1.5)^2}{4} \times \sqrt{2 \times 32.16 \times 4} = 13.3 \text{ c.f.s.}$$

which is okay. An 18-inch diameter culvert pipe is satisfactory. Capacities of culverts are given in Figures 16.24, 16.25, and 16.26. The type of culvert and conditions affecting the flow are given at the top of each table.

Design of Inverted Siphons

To find the size of an inverted siphon to carry a given amount of water, similar procedures are used as for determining flow through small pipes previously described. All of the losses are determined in terms of head expressed in feet. The sum of all of these losses is the head, or difference in elevation between the ends of the siphon, necessary to carry the desired quantity of water. The losses to be considered are shown below:

H = the total head.
H_v = head required to give the necessary velocity.
H_f = head required to overcome friction in pipe.
H_e = head required to overcome friction at entrance.
H_b = loss of head due to bends. (This may be expressed in terms of H_f by using equivalent length of pipe for each bend as shown in Figure 16.28.)

The formula for the total head is $H = H_v + H_e + H_f + H_b$. Figure 16.29 gives H_f in feet per 100 feet of corrugated pipe, also area of pipe in square feet, and velocity in feet per second when the pipe is carrying a given amount of water.

Example of Inverted Siphon Design. Figure 16.27 shows a typical inverted siphon installation. Procedures of design are shown in the following example:

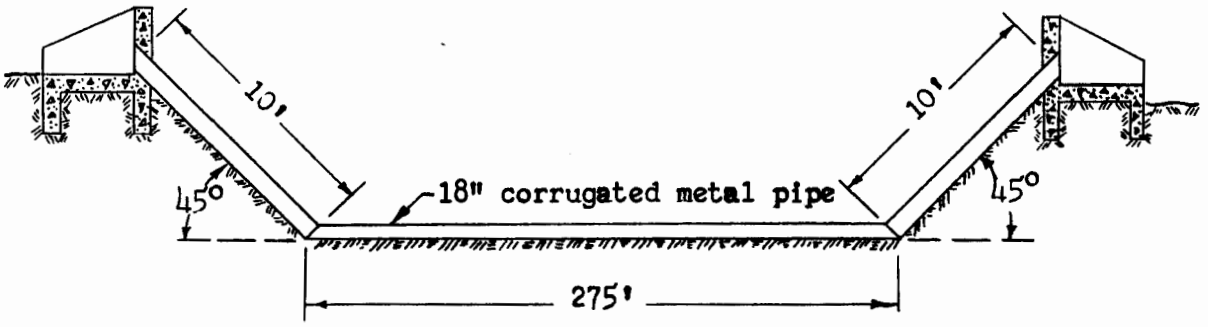


Figure 16.27

LOSS OF HEAD IN ELBOWS EXPRESSED IN EQUIVALENT LENGTH OF PIPE
(SQUARE ELBOWS - NO ROUNDING OF CORNERS)
(FOR CORRUGATED METAL PIPE, n = 0.025)

	Pipe Diameter				
Elbow	12"	15"	18"	21"	24"
90°	13	17	22	27	33
45°	10	13	17	21	25

Fig. 16.28

FRICTION HEAD LOSS PER 100 FEET IN CORRUGATED PIPE
AND VELOCITIES IN FEET PER SECOND
FOR QUANTITIES OF WATER FROM 0.5 TO 10 C.F.S.
n = 0.025

Cubic feet per second	Diam - 12" Area - 0.785 square feet		Diam - 15" Area - 1.227 square feet		Diam - 18" Area - 1.767 square feet		Diam - 21" Area - 2.405 square feet		Diam - 24" Area - 3.142 square feet	
	H_f	Vel.	H_f	Vel.	H_f	Vel.	H_f	Vel.	H_f	Vel.
.5	.07	.64	.02	.41	.01	.28	---	.21	---	.16
1.0	.29	1.27	.09	.81	.03	.57	.01	.42	.01	.32
1.5	.65	1.91	.20	1.22	.08	.85	.03	.62	.02	.48
2.0	1.16	2.55	.35	1.63	.13	1.13	.06	.83	.03	.64
2.5	1.82	3.18	.55	2.04	.21	1.41	.09	1.04	.04	.80
3.0	2.62	3.82	.80	2.44	.30	1.70	.13	1.25	.06	.95
3.5	3.57	4.46	1.08	2.85	.41	1.98	.18	1.46	.09	1.11
4.0	4.66	5.09	1.42	3.26	.54	2.26	.24	1.66	.12	1.27
4.5	5.89	5.73	1.79	3.67	.68	2.55	.30	1.87	.15	1.43
5.0	7.28	6.37	2.21	4.07	.84	2.83	.37	2.08	.18	1.59
6.0	10.48	7.64	3.19	4.89	1.21	3.40	.53	2.49	.26	1.91
7.0	14.26	8.91	4.34	5.70	1.64	3.96	.72	2.91	.35	2.23
8.0	18.63	10.19	5.67	6.52	2.14	4.53	.94	3.33	.46	2.55
9.0	23.58	11.46	7.18	7.33	2.71	5.09	1.19	3.74	.58	2.86
10.0	29.11	12.73	8.86	8.15	3.35	5.66	1.47	4.16	.72	3.18

Fig. 16.29

5. PIPE FLOW (CONT'D)

Design of Inverted Siphons (cont'd)

Given: A siphon as shown, to carry 4 cubic feet per second. Velocity in ditch is 2 feet per second.

Find: Size of pipe and required head (H).

$$H = H_v + H_e + H_f + H_b$$

Assume that an 18-inch corrugated pipe is large enough. From Figure 16.29 find that the velocity in an 18-inch corrugated pipe is 2.26 f.s. when the pipe is carrying 4 c.f.s. Also from the same table H_f = .54 per 100 feet of pipe. Look up the value of H_v in Figure 16.18 when the velocity is 2.26. This is found (by interpolation) to be .08 feet. H_e for a sharp-cornered entrance is found to be .04 feet.

H_f = .54 x 2.95 (length of pipe in hundreds of feet) = 1.59
H_b = for one 45-degree elbow Figure 16.28 is found to be equivalent to the loss of head in 17 feet of pipe, or .09 feet. For two elbows, H_b = 2 x .09 = .18 feet.
H = .08 + .04 + 1.59 + .18 = 1.89

If there is 1.89 feet of fall from the inlet water surface to the outlet water surface, the 18-inch pipe is satisfactory. If more than 1.89 feet is available, solve the problem again using a smaller pipe. If there is less than 1.89 feet available, solve again using a larger pipe.

Closed Conduit Spillways

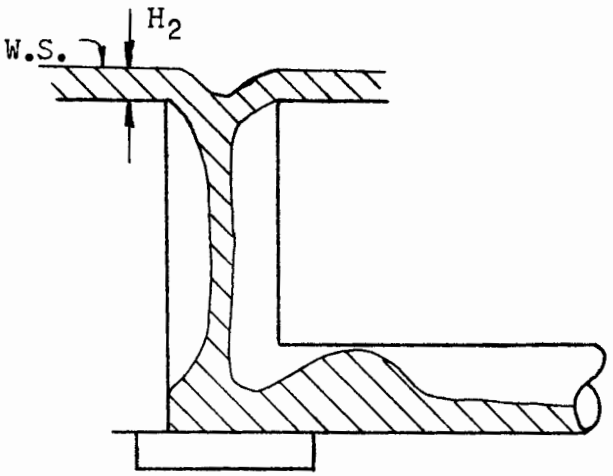
Definition. This type of spillway is known by a number of different names which are commonly associated with the different uses to which the spillway is put. The most common of these names are Drop Inlet Spillway and Trickle Tube Spillway.

As used here, a closed conduit spillway will mean a pipe culvert including an entrance and outlet. The culvert may consist of a barrel on a flat or steep slope connected to a vertical riser as shown in Figure 16.30 or may consist of a straight pipe on a flat or steep slope.

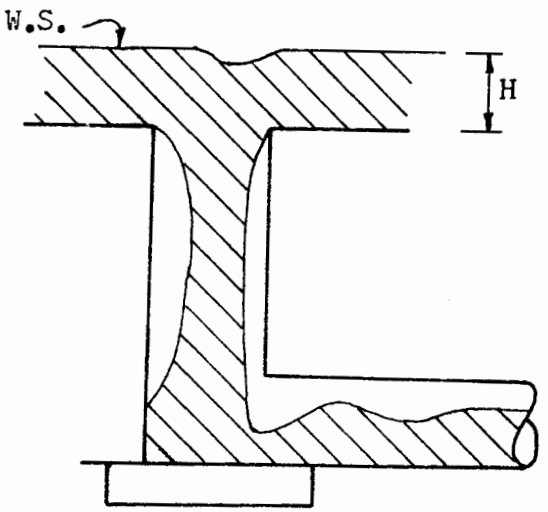
Materials. Metal pipe, precast concrete pipe, or poured concrete is used for closed conduit spillways.

Drop Inlet Spillways. Drop Inlet Spillways should be designed such that the riser diameter is at least 1.25 times the diameter of the barrel. In determining weir flow conditions, the weir length "L" for a circular riser with a headwall is 2.57 times the diameter of the riser.

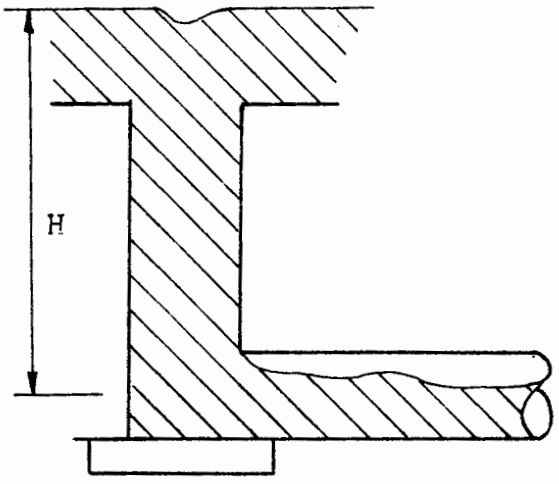
Capacity of Drop Inlet Spillways. A number of different equations are used to compute the flow through drop inlet spillways. A discussion of these equations are considered beyond the scope of this Handbook and will not be covered. For complete information regarding this subject, reference



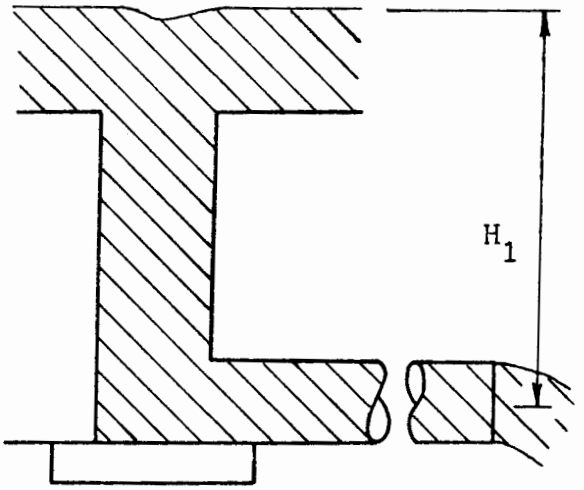
Weir Control at Entrance



Orifice Control at Crest of Riser



Orifice Control at Entrance of Barrel or Short Tube Control



Full Pipe Flow

Figure 16.30

5. PIPE FLOW (CONT'D)

Closed Conduit Spillways (cont'd)

Capacity of Drop Inlet Spillways (cont'd)

is made to Technical Paper No. 12, Series B Hydraulics of Closed Conduit Spillways, Part 1. Theory and Its Application, by USDA-SCS-Research.

For the purposes of this discussion, it is considered that coverage will be confined to conditions which control discharge and to the use of developed tables which are applicable to solution of simple drop inlet design for corrugated pipe.

Weir flow at the conduit entrance may control the capacity. Discharges for this condition are given in Figure 16.32. Secondly, discharge may be controlled by an orifice at the crest of the riser or at the barrel entrance. Discharges for these conditions are given in Figure 16.33-1 and Figure 16.33-2. The discharge may be controlled by the entire conduit flowing full. Discharges for this condition are given in Figure 16.34-1 and Figure 16.34-2. Figure 16.35 is head discharge tables for weir, orifice, and full pipe flow for small diameter corrugated pipe used as trickle tubes.

For a given head condition and pipe sizes and lengths, all four conditions should be evaluated from the tables. The lowest value thus determined will be the actual and controlling discharge of the spillway.

Figure 16.30 shows the type of flow control which may exist in a drop inlet spillway.

Example of Drop Inlet Flow Determination

The solution of the following example is presented for conditions given in Figure 16.31.

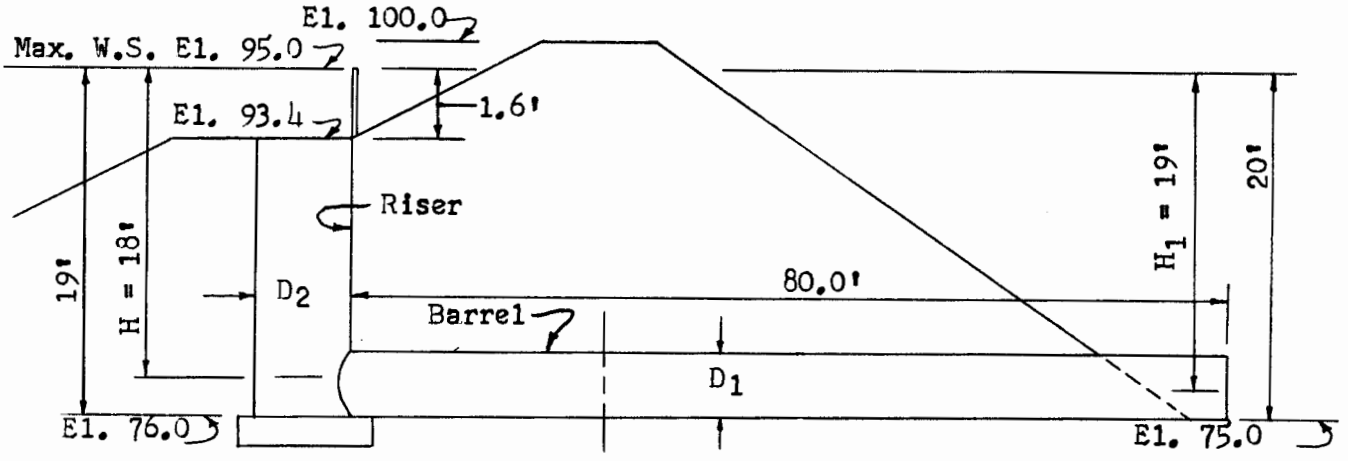


Figure 16.31

HEAD DISCHARGE TABLE FOR CORRUGATED METAL PIPE DROP INLETS (WEIR FLOW CONDITION)

Riser Diameter Inches	Head in Feet												
	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6
15	2.7	3.8	4.9	6.3	ORIFICE								
18	3.2	4.5	5.9	7.6	9.3	10.9	FLOW						
21	3.8	5.3	7.0	8.8	10.7	12.8	15.0	CONDITIONS					
24	4.3	6.0	7.9	10.1	12.3	14.6	17.1	19.7	22.4	CONTROL			
30	5.4	7.5	9.8	12.6	15.4	18.2	21.4	24.6	28.0	31.7	35.5		
36	6.4	9.0	11.8	15.1	18.5	21.8	25.7	29.5	33.6	38.0	42.6	47.2	51.9
42	7.5	10.5	13.8	17.7	21.6	25.5	30.0	34.5	39.3	44.4	49.8	55.1	60.5
48	8.6	12.0	15.7	20.2	24.6	29.1	34.2	39.4	44.8	50.7	56.8	63.0	69.1
54	9.6	13.5	17.7	22.7	27.7	32.8	38.5	44.3	50.5	57.0	64.0	70.9	77.8
60	10.7	15.0	19.7	25.2	30.8	36.4	42.8	49.2	56.1	63.3	71.0	78.7	86.4

Riser Diameter Inches	Head in Feet								
	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5
42	66.5	72.5	ORIFICE FLOW						
48	76.0	82.8	89.7	96.9	104.1	CONDITIONS CONTROL			
54	85.5	93.2	100.9	109.0	117.1	125.6	134.5	143.3	
60	95.0	103.6	112.1	121.1	130.1	139.5	149.3	159.2	169.0

NOTES: (1) The discharge capacities shown in this table are based on the formula:

$$Q_2 = C_2 L H_2^{3/2}$$

Q_2 = discharge capacity of weir, in c.f.s.
C_2 = weir coefficient = 3.33
L = length of weir crest, in feet (for circular riser with headwall, L = 2.57 times diameter of riser).
H_2 = distance from crest of riser to water surface in reservoir, in feet.

(2) The diameter of the riser should be at least 1¼ times the diameter of barrel.

(3) Use this table in conjunction with orifice flow and full pipe flow conditions to determine capacity of the drop inlet.

Figure 16.32

HEAD DISCHARGE TABLE FOR CORRUGATED METAL PIPE
DROP INLETS
(Orifice Control Conditions at Crest of Riser or Entrance to Barrel)

Dia. Inches	Head in Feet																
	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0
12	4.1	5.0	5.8	6.3	7.1	7.7	8.2	8.7	9.1	9.6	10.0	10.4	10.8	11.2	11.6	11.9	12.3
15	6.7	8.2	9.5	10.6	11.6	12.6	13.4	14.3	15.0	15.8	16.5	17.1	17.8	18.4	19.0	19.6	20.2
18	10.1	12.3	14.3	16.0	17.5	18.9	20.2	21.4	22.5	23.6	24.7	25.7	26.7	27.6	28.5	29.4	30.2
21	13.8	17.0	19.6	21.9	24.0	25.9	27.7	29.4	31.0	32.5	33.9	35.3	36.6	37.9	39.2	40.4	41.6
24		22.5	26.1	29.2	32.0	34.5	36.8	39.0	41.1	43.1	45.0	46.9	48.6	50.3	52.0	53.6	55.1
30		35.2	40.8	45.4	49.9	53.8	57.5	61.0	64.3	67.4	70.4	73.3	76.1	78.7	81.3	83.8	86.2
36	Weir		58.7	65.7	71.9	77.8	82.9	87.9	92.7	97.2	101.5	105.7	109.7	113.5	117.2	120.8	124.4
42	Flow		79.8	88.2	97.7	105.5	112.6	119.5	125.9	132.1	137.9	143.6	149.0	154.2	159.3	164.2	169.0
48	Controls			115.0	125.5	136.0	145.2	154.0	162.3	170.2	177.8	185.0	192.1	198.7	205.3	211.6	217.8

Figure 16.33-1

Dia. Inches	Head in Feet																
	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	16.0	17.0	18.0	19.0	20.0
12	12.6	12.9	13.3	13.6	13.9	14.2	14.5	14.8	15.0	15.3	15.6	15.8	16.4	16.9	17.4	17.8	18.3
15	20.7	21.2	21.8	22.3	22.8	23.3	23.8	24.2	24.7	25.1	25.6	26.1	26.9	27.7	28.5	29.3	30.0
18	31.1	31.9	32.7	33.4	34.2	34.9	35.6	36.4	37.0	37.7	38.4	39.0	40.3	41.6	42.8	43.9	45.1
21	42.7	43.8	44.9	46.0	47.0	47.9	49.0	50.0	50.9	51.8	52.8	53.6	55.4	57.0	58.8	60.4	61.9
24	56.7	58.1	59.6	61.0	62.3	63.7	65.0	66.3	67.6	68.8	70.0	71.2	73.5	75.8	78.0	80.1	82.2
30	88.6	90.9	93.1	95.4	97.4	99.6	101.6	103.7	105.6	107.6	109.5	111.3	115.0	118.5	122.0	125.3	128.6
36	127.8	131.1	134.3	137.5	140.5	143.6	146.5	149.5	152.3	155.1	157.8	160.5	165.8	170.9	175.9	180.7	185.4
42	173.6	178.1	182.5	186.8	190.9	195.1	199.1	203.1	207.0	210.8	214.5	218.1	225.3	232.2	239.0	245.5	251.9
48	223.7	229.5	235.2	240.8	246.1	251.4	256.6	261.7	266.7	271.6	276.4	281.1	290.3	299.3	308.0	316.4	324.6

NOTES: (1) Discharge based on formula $Q = C\,A\,\sqrt{2\,g\,H}$ where

Q = discharge in c.f.s.; C = orifice coefficient = "C" from Figure 16.22 for 10 foot length minus 0.02 x pipe diameter in feet; A = cross sectional area, in feet.

H = distance from center of barrel at the inlet to water surface for control of the entrance to the barrel or distance from the top of the riser to the water surface for control at the crest of the riser.

g = acceleration due to gravity (32.2 ft./sec.^{2}).

(2) Use this table in conjunction with weir flow and full pipe flow conditions to determine capacity of drop inlet.

Figure 16.33-2

HEAD DISCHARGE TABLE FOR CORRUGATED METAL PIPE DROP INLETS

(FULL PIPE FLOW CONDITION)

Barrel Diameter in inches	Length in feet	Head in Feet															
		5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5
12	60	5.1	5.3	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.3	7.5	7.7	7.9	8.0
	70	4.8	5.0	5.2	5.5	5.7	5.9	6.1	6.2	6.4	6.6	6.8	6.9	7.1	7.3	7.4	7.6
	80	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.0	6.2	6.4	6.5	6.7	6.8	7.0	7.1
	90	4.4	4.6	4.8	5.0	5.2	5.3	5.5	5.7	5.9	6.0	6.2	6.3	6.5	6.6	6.8	6.9
	100	4.1	4.3	4.5	4.7	4.8	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.1	6.2	6.3	6.5
	110	3.9	4.1	4.3	4.5	4.7	4.8	5.0	5.1	5.3	5.4	5.6	5.7	5.8	6.0	6.1	6.2
	120	3.8	4.0	4.2	4.3	4.5	4.7	4.8	5.0	5.1	5.2	5.4	5.5	5.6	5.8	5.9	6.0
	130	3.7	3.8	4.0	4.2	4.3	4.5	4.6	4.8	4.9	5.0	5.2	5.3	5.4	5.5	5.7	5.8
	140	3.5	3.7	3.9	4.0	4.2	4.3	4.4	4.6	4.7	4.9	5.0	5.1	5.2	5.3	5.5	5.6
18	60	14.0	14.6	15.3	15.9	16.5	17.1	17.7	18.2	18.7	19.3	19.7	20.2	20.7	21.2	21.6	22.1
	70	13.3	14.0	14.6	15.2	15.8	16.3	16.9	17.4	17.9	18.4	18.9	19.3	19.8	20.2	20.7	21.1
	80	12.7	13.3	13.9	14.8	15.0	15.5	16.1	16.6	17.0	17.5	18.0	18.4	18.8	19.2	19.7	20.1
	90	12.1	12.6	13.2	13.7	14.3	14.8	15.3	15.7	16.2	16.6	17.1	17.5	17.9	18.3	18.7	19.1
	100	11.4	12.0	12.5	13.0	13.5	14.0	14.5	14.9	15.3	15.7	16.2	16.6	16.9	17.3	17.7	18.1
	110	11.1	11.6	12.2	12.7	13.1	13.6	14.0	14.5	14.9	15.3	15.7	16.1	16.5	16.8	17.2	17.6
	120	10.5	11.0	11.5	11.9	12.4	12.8	13.2	13.7	14.1	14.4	14.8	15.2	15.5	15.9	16.2	16.6
	130	10.2	10.7	11.1	11.6	12.0	12.4	12.8	13.2	13.6	14.0	14.4	14.7	15.1	15.4	15.7	16.1
	140	9.8	10.3	10.8	11.2	11.6	12.0	12.4	12.8	13.2	13.6	13.9	14.3	14.6	14.9	15.2	15.6
24	60	28.2	29.5	30.8	32.1	33.3	34.5	35.6	36.7	37.8	38.8	39.8	40.8	41.8	42.7	43.6	44.5
	70	26.5	27.8	29.0	30.2	31.3	32.4	33.5	34.5	35.5	36.5	37.4	38.3	39.3	40.1	41.0	41.8
	80	25.3	26.6	27.8	28.9	30.0	31.0	32.0	33.0	34.0	34.9	35.8	36.7	37.6	38.4	39.3	40.1
	90	24.2	25.4	26.5	27.6	28.7	29.6	30.6	31.6	32.5	33.4	34.2	35.1	35.9	36.7	37.5	38.3
	100	23.1	24.2	25.3	26.3	27.3	28.3	29.2	30.1	31.0	31.8	32.6	33.5	34.2	35.0	35.8	36.5
	110	22.5	23.6	24.7	25.7	26.7	27.6	28.5	29.4	30.2	31.0	31.9	32.6	33.4	34.1	34.9	35.6
	120	21.4	22.4	23.4	24.4	25.3	26.2	27.1	27.9	28.7	29.5	30.3	31.0	31.7	32.4	33.2	33.8
	130	20.8	21.9	22.8	23.8	24.7	25.5	26.4	27.2	28.0	28.7	29.5	30.2	30.9	31.6	32.3	32.9
	140	20.3	21.3	22.2	23.1	24.0	24.8	25.6	26.4	27.2	27.9	28.7	29.4	30.1	30.7	31.4	32.0
30	60	47.5	49.9	52.1	54.2	56.3	58.2	60.1	62.0	63.8	65.5	67.2	68.9	70.5	72.1	73.7	75.2
	70	45.8	48.0	50.1	52.2	54.2	56.1	57.9	59.7	61.4	63.1	64.7	66.3	67.9	69.4	70.9	72.4
	80	43.1	45.2	47.3	49.2	51.2	52.8	54.6	56.2	57.9	59.5	61.0	62.5	64.0	65.4	66.8	68.2
	90	41.4	43.4	45.3	47.2	49.0	50.7	52.3	54.0	55.5	57.0	58.5	60.0	61.4	62.7	64.1	65.4
	100	40.5	42.5	44.4	46.2	47.9	49.6	51.2	52.8	54.3	55.8	57.3	58.7	60.1	61.4	62.7	64.0
	110	38.7	40.6	42.4	44.2	45.8	47.4	49.0	50.5	52.0	53.4	54.8	56.1	57.5	58.7	60.0	61.2
	120	37.9	39.7	41.5	43.2	44.8	46.4	47.9	49.4	50.8	52.2	53.5	54.9	56.2	57.4	58.7	59.9
	130	36.1	37.9	39.5	41.2	42.7	44.2	45.7	47.1	48.4	49.8	51.1	52.3	53.6	54.7	55.9	57.1
	140	35.2	36.9	38.6	40.1	41.7	43.1	44.5	45.9	47.3	48.5	49.8	51.0	52.2	53.4	54.6	55.7
36	60	73.6	77.2	80.7	83.9	87.1	90.2	93.1	96.0	98.8	101.5	104.1	106.7	109.2	111.6	114.1	116.4
	70	69.8	73.2	76.5	79.6	82.6	85.5	88.3	91.0	93.7	96.3	98.7	101.2	103.6	105.9	108.2	110.4
	80	67.3	70.6	73.7	76.7	79.6	82.4	85.1	87.7	90.3	92.7	95.2	97.5	99.8	102.0	104.2	106.4
	90	64.8	67.9	70.9	73.8	76.6	79.3	81.9	84.4	86.9	89.3	91.6	93.8	96.1	98.2	100.3	102.4
	100	62.2	65.2	68.1	70.9	73.6	76.2	78.7	81.1	83.5	85.8	88.0	90.1	92.3	94.3	96.4	98.4
	110	60.9	63.9	66.7	69.5	72.1	74.6	77.1	79.4	81.8	84.0	86.2	88.3	90.4	92.4	94.4	96.3
	120	58.4	61.3	64.0	66.6	69.2	71.5	73.9	76.1	78.4	80.5	82.6	84.6	86.6	88.5	90.5	92.3
	130	57.1	59.9	62.6	65.1	67.6	70.0	72.3	74.5	76.7	78.8	80.8	82.8	84.8	86.6	88.5	90.3
	140	55.9	58.6	61.2	63.7	66.1	68.4	70.7	72.8	75.0	77.0	79.0	80.9	82.9	84.7	86.5	88.3
42	60	103.5	108.6	113.4	118.0	122.5	126.7	130.9	134.9	138.9	142.7	146.4	150.0	153.5	156.9	160.4	163.6
	70	100.1	104.9	109.6	114.1	118.4	122.5	126.5	130.4	134.2	137.9	141.5	145.0	148.4	151.7	155.0	158.2
	80	96.6	101.3	105.8	110.1	114.3	118.3	122.2	125.9	129.6	133.2	136.6	140.0	143.3	146.5	149.7	152.7
	90	93.2	97.7	102.0	106.2	110.2	114.1	117.8	121.4	125.0	128.4	131.7	135.0	138.2	141.2	144.3	147.3
	100	89.7	94.1	98.3	102.3	106.2	109.8	113.5	116.9	120.4	123.6	126.9	130.0	133.1	136.0	139.0	141.8
	110	86.3	90.5	94.5	98.3	102.1	105.6	109.1	112.4	115.7	118.9	122.0	125.0	128.0	130.8	133.6	136.4
	120	84.5	88.7	92.6	96.4	100.0	103.5	106.9	110.2	113.4	116.5	119.5	122.5	125.4	128.2	131.0	133.6
	130	82.8	86.8	90.7	94.4	98.0	101.4	104.7	108.0	111.1	114.1	117.1	120.0	122.8	125.5	128.3	130.9
	140	79.4	83.2	86.9	90.5	93.9	97.2	100.4	103.5	106.5	109.4	112.2	115.0	117.7	120.3	122.9	125.5
48	60	139.8	146.6	153.1	159.3	165.4	171.1	176.8	182.2	187.5	192.6	197.6	202.5	207.3	211.9	216.5	220.9
	70	135.2	141.8	148.1	154.2	160.0	165.6	171.1	176.3	181.5	186.4	191.3	196.0	200.6	205.0	209.5	213.8
	80	130.7	137.1	143.2	149.0	154.7	160.1	165.4	170.4	175.4	180.2	184.9	189.4	193.9	198.2	202.5	206.7
	90	126.2	132.4	138.3	143.9	149.4	154.6	159.7	164.6	169.4	174.0	178.5	182.9	187.3	191.4	195.6	199.6
	100	121.7	127.7	133.3	138.8	144.0	149.0	153.9	158.7	163.3	167.8	172.1	176.4	180.6	184.5	188.6	192.4
	110	119.5	125.3	130.8	136.2	141.4	146.3	151.1	155.7	160.3	164.7	168.9	173.1	177.2	181.1	185.1	188.9
	120	115.0	120.6	125.9	131.1	136.0	140.8	145.4	149.9	154.2	158.5	162.6	166.6	170.5	174.3	178.1	181.7
	130	112.7	118.2	123.4	128.5	133.4	138.0	142.5	146.9	151.2	155.3	159.4	163.3	167.2	170.9	174.6	178.2
	140	110.5	115.8	121.0	125.9	130.7	135.2	139.7	144.0	148.2	152.2	156.2	160.0	163.8	167.5	171.1	174.6

Figure 16.34-1

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HEAD DISCHARGE TABLE FOR CORRUGATED METAL PIPE DROP INLETS
(FULL PIPE FLOW CONDITION)

Barrel Diameter in inches	Barrel Length in feet	Head in Feet 13.0	13.5	14.0	14.5	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0
12	60	8.2	8.3	8.5	8.6	8.8	9.1	9.3	9.6	9.9	10.1	10.4	10.6	10.9	11.1	11.3	11.6
	70	7.7	7.9	8.0	8.2	8.3	8.6	8.8	9.1	9.3	9.6	9.8	10.0	10.3	10.5	10.7	10.9
	80	7.3	7.4	7.5	7.7	7.8	8.1	8.3	8.5	8.8	9.0	9.2	9.4	9.7	9.9	10.1	10.3
	90	7.0	7.2	7.3	7.4	7.6	7.8	8.0	8.3	8.5	8.7	8.9	9.2	9.4	9.6	9.8	10.0
	100	6.6	6.7	6.8	7.0	7.1	7.3	7.5	7.7	8.0	8.2	8.4	8.6	8.8	8.9	9.1	9.3
	110	6.4	6.5	6.6	6.7	6.8	7.1	7.3	7.5	7.7	7.9	8.1	8.3	8.5	8.6	8.8	9.0
	120	6.1	6.2	6.4	6.5	6.6	6.8	7.0	7.2	7.4	7.6	7.8	8.0	8.2	8.3	8.5	8.7
	130	5.9	6.0	6.1	6.2	6.3	6.5	6.7	6.9	7.1	7.3	7.5	7.7	7.9	8.0	8.2	8.3
	140	5.7	5.8	5.9	6.0	6.1	6.3	6.5	6.7	6.9	7.0	7.2	7.4	7.5	7.7	7.9	8.0
18	60	22.5	23.0	23.4	23.8	24.2	25.0	25.8	26.5	27.2	27.9	28.6	29.3	30.0	30.6	31.2	31.8
	70	21.5	21.9	22.3	22.7	23.1	23.8	24.6	25.3	26.0	26.7	27.3	28.0	28.6	29.2	29.8	30.4
	80	20.5	20.9	21.2	21.6	22.0	22.7	23.4	24.1	24.6	25.4	26.0	26.6	27.2	27.8	28.4	29.0
	90	19.5	19.8	20.2	20.5	20.9	21.6	22.2	22.9	23.5	24.1	24.7	25.3	25.9	26.4	27.0	27.5
	100	18.4	18.8	19.1	19.5	19.8	20.4	21.1	21.7	22.3	22.9	23.4	24.0	24.5	25.0	25.6	26.1
	110	17.9	18.3	18.6	18.9	19.2	19.9	20.5	21.1	21.7	22.2	22.8	23.3	23.8	24.3	24.8	25.3
	120	16.9	17.2	17.5	17.8	18.1	18.7	19.3	19.9	20.4	20.9	21.5	22.0	22.5	22.9	23.4	23.9
	130	16.4	16.7	17.0	17.3	17.6	18.2	18.7	19.3	19.8	20.3	20.8	21.3	21.8	22.3	22.7	23.2
	140	15.9	16.2	16.5	16.8	17.0	17.6	18.1	18.7	19.2	19.7	20.2	20.6	21.1	21.6	22.0	22.4
24	60	45.4	46.3	47.1	48.0	48.8	50.4	51.9	53.4	54.9	56.3	57.7	59.1	60.4	61.7	63.0	64.2
	70	42.7	43.5	44.3	45.1	45.8	47.3	48.8	50.2	51.6	52.9	54.2	55.5	56.8	58.0	59.2	60.4
	80	40.9	41.6	42.4	43.2	43.9	45.3	46.7	48.1	49.4	50.7	51.9	53.1	54.3	55.5	56.7	57.8
	90	39.0	39.8	40.5	41.2	41.9	43.3	44.6	45.9	46.2	48.4	49.6	50.8	51.9	53.1	54.1	55.2
	100	37.2	37.9	38.6	39.3	40.0	41.3	42.6	43.8	45.0	46.2	47.3	48.4	49.5	50.6	51.6	52.6
	110	36.3	37.0	37.7	38.4	39.0	40.3	41.5	42.7	43.9	45.0	46.2	47.2	48.3	49.3	50.4	51.4
	120	34.5	35.2	35.8	36.4	37.1	38.3	39.5	40.6	41.7	42.8	43.9	44.9	45.9	46.9	47.9	48.8
	130	33.6	34.2	34.9	35.5	36.1	37.3	38.4	39.5	40.6	41.7	42.7	43.7	44.7	45.6	46.6	47.5
	140	32.7	33.3	33.9	34.5	35.1	36.3	37.4	38.5	39.5	40.5	41.5	42.5	43.5	44.4	45.3	46.2
30	60	76.7	78.1	79.6	81.0	82.4	85.1	87.7	90.2	92.7	95.1	97.5	99.7	102.0	104.2	106.3	108.4
	70	73.8	75.3	76.6	78.0	79.3	81.9	84.4	86.9	89.3	91.6	93.8	96.0	98.2	100.3	102.4	104.4
	80	69.6	70.9	72.2	73.5	74.7	77.2	79.6	81.9	84.1	86.3	88.4	90.5	92.5	94.5	96.5	98.4
	90	66.7	68.0	69.3	70.5	71.7	74.0	76.3	78.5	80.7	82.8	84.8	86.8	88.8	90.7	92.5	94.4
	100	65.3	66.6	67.8	69.0	70.2	72.5	74.7	76.9	79.0	81.0	83.0	85.0	86.9	88.7	90.6	92.4
	110	62.5	63.7	64.8	66.0	67.1	69.3	71.4	73.5	75.5	77.5	79.4	81.3	83.1	84.9	86.6	88.3
	120	61.1	62.2	63.4	64.5	65.6	67.7	69.8	71.8	73.8	75.7	77.6	79.4	81.2	83.0	84.7	86.3
	130	58.2	59.3	60.4	61.5	62.5	64.6	66.6	68.5	70.4	72.2	74.0	75.7	77.4	79.1	80.7	82.3
	140	56.8	57.9	58.9	60.0	61.0	63.0	64.9	66.8	68.7	70.4	72.2	73.9	75.5	77.2	78.8	80.3
36	60	118.8	121.0	123.2	125.4	127.6	131.7	135.8	139.7	143.6	147.3	150.9	154.5	158.0	161.3	164.7	167.9
	70	112.6	114.8	116.9	118.9	121.0	124.9	128.8	132.5	136.1	139.7	143.1	146.5	149.8	153.0	156.2	159.2
	80	108.5	110.6	112.6	114.6	116.6	120.4	124.1	127.7	131.2	134.6	137.9	141.1	144.3	147.4	150.5	153.4
	90	104.4	106.4	108.4	110.3	112.2	115.8	119.4	122.9	126.2	129.5	132.7	135.8	138.9	141.9	144.8	147.7
	100	100.3	102.2	104.1	105.9	107.8	111.3	114.7	118.1	121.3	124.4	127.5	130.5	133.4	136.3	139.1	141.9
	110	98.3	100.2	102.0	103.8	105.6	109.0	112.4	115.6	118.8	121.9	124.9	127.8	130.7	133.5	136.3	139.0
	120	94.2	96.0	97.7	99.5	101.2	104.5	107.7	110.8	113.9	116.8	119.7	122.5	125.3	128.0	130.6	133.2
	130	92.1	93.9	95.6	97.3	99.0	102.2	105.4	108.4	111.4	114.3	117.1	119.8	122.5	125.2	127.8	130.3
	140	90.1	91.8	93.5	95.1	96.8	99.9	103.0	106.0	108.9	111.7	114.5	117.2	119.8	122.4	124.9	127.4
42	60	166.9	170.1	173.2	176.3	179.3	185.2	190.9	196.4	201.8	207.0	212.2	217.1	222.0	226.8	231.5	236.0
	70	161.4	164.4	167.4	170.4	173.3	179.0	184.5	189.9	195.1	200.1	205.1	209.9	214.6	219.2	223.7	228.2
	80	155.8	158.8	161.7	164.5	167.3	172.8	178.1	183.3	188.3	193.2	198.0	202.6	207.2	211.7	216.0	220.3
	90	150.2	153.1	155.9	158.6	161.4	166.6	171.8	176.8	181.6	186.3	190.9	195.4	199.8	204.1	208.1	212.4
	100	144.7	147.4	150.1	152.8	155.4	160.5	165.4	170.2	174.9	179.4	183.9	188.2	192.4	196.5	200.6	204.6
	110	139.1	141.8	144.4	146.9	149.4	154.3	159.0	163.7	168.2	172.5	176.8	180.9	185.0	189.0	192.9	196.7
	120	136.3	138.9	141.5	144.0	146.4	151.2	155.9	160.4	164.8	169.1	173.3	177.3	181.3	185.2	189.0	192.8
	130	133.5	136.1	138.6	141.0	143.4	148.1	152.7	157.1	161.4	165.6	169.7	173.7	177.6	181.4	185.2	188.8
	140	128.0	130.4	132.8	135.1	137.5	142.0	146.3	150.6	154.7	158.7	162.7	166.4	170.2	173.9	177.5	181.0
48	60	225.4	229.7	233.9	238.0	242.1	250.0	257.7	265.2	272.4	279.5	286.4	293.1	299.8	306.2	312.5	318.7
	70	218.1	222.3	226.3	230.3	234.3	241.9	249.4	256.6	263.7	270.5	277.2	283.7	290.1	296.3	302.4	308.4
	80	210.8	214.9	218.8	222.7	226.5	233.9	241.1	248.1	254.9	261.5	268.0	274.2	280.4	286.4	292.4	298.1
	90	203.6	207.5	211.3	215.0	218.6	225.8	232.8	239.5	246.1	252.5	258.7	264.8	270.8	276.6	282.3	287.9
	100	196.3	200.1	203.7	207.3	210.8	217.7	224.4	231.0	237.3	243.4	249.5	255.3	261.1	266.7	272.2	277.6
	110	192.7	196.4	199.9	203.5	206.9	213.7	220.3	226.7	232.9	238.9	244.9	250.6	256.2	261.7	267.1	272.4
	120	185.4	188.9	192.4	195.8	199.1	205.7	212.0	218.1	224.1	229.9	235.6	241.1	246.6	251.9	257.1	262.2
	130	181.8	185.2	188.6	191.9	195.2	201.6	207.8	213.9	219.7	225.4	231.0	236.4	241.7	246.9	252.0	257.0
	140	178.1	181.5	184.8	188.1	191.3	197.6	203.7	209.6	215.3	220.9	226.4	231.7	236.9	242.0	247.0	251.9

Notes: (1) The discharge capacities shown in this table are based on the formula $Q_1 = C_1 A_1 \sqrt{2gH_1}$ where Q_1=discharge capacity of full pipe, in c.f.s; C_1=coefficient for corrugated metal pipe from King's "Handbook of Hydraulics", page 79 (old edition) or page 3-42 (new edition); A_1=cross-sectional area of barrel, in sq. ft.; g=acceleration due to gravity (32.2 ft./sec^2); H_1=difference in elevation of water surface in reservoir and water surface at outlet for submerged flow or center of barrel at outlet for free discharge, in feet.

(2) Use this table in conjunction with orifice flow and weir flow conditions to determine capacity of the drop inlet.

Figure 16.34-2

HEAD DISCHARGE TABLE FOR SMALL CORRUGATED METAL PIPE DROP INLETS USED AS TRICKLE TUBES
(FULL PIPE FLOW CONDITIONS)

BARREL Diam. In.	BARREL Length Feet	Head in Feet 5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5	12.0	12.5	13.0	13.5	14.0	14.5	15.0	15.5
6	60	.89	.93	.97	1.01	1.05	1.09	1.12	1.16	1.19	1.22	1.25	1.28	1.31	1.34	1.37	1.40	1.43	1.46	1.48	1.51	1.54	1.56
	70	.83	.87	.91	.94	.98	1.01	1.05	1.08	1.11	1.14	1.17	1.20	1.23	1.25	1.28	1.31	1.33	1.36	1.38	1.41	1.43	1.46
	80	.78	.81	.85	.88	.92	.95	.98	1.01	1.04	1.07	1.10	1.12	1.15	1.18	1.20	1.23	1.25	1.27	1.30	1.32	1.34	1.37
	90	.73	.77	.80	.84	.87	.90	.93	.96	.98	1.01	1.04	1.06	1.09	1.11	1.14	1.16	1.18	1.21	1.23	1.25	1.27	1.29
	100	.70	.73	.76	.80	.83	.85	.88	.91	.94	.96	.99	1.01	1.03	1.06	1.08	1.10	1.12	1.15	1.17	1.19	1.21	1.23
	110	.67	.70	.73	.76	.79	.82	.84	.87	.90	.92	.94	.97	.99	1.01	1.03	1.06	1.08	1.10	1.12	1.14	1.16	1.17
	120	.64	.67	.70	.73	.76	.78	.81	.83	.86	.88	.90	.93	.95	.97	.99	1.01	1.03	1.05	1.07	1.09	1.11	1.12
	130	.62	.65	.67	.70	.73	.75	.78	.80	.83	.85	.87	.89	.91	.93	.95	.97	.99	1.01	1.03	1.05	1.07	1.09
	140	.59	.63	.65	.68	.70	.73	.75	.77	.80	.82	.84	.86	.88	.90	.92	.94	.96	.98	.99	1.01	1.03	1.05
8	60	1.85	1.94	2.02	2.10	2.19	2.26	2.34	2.41	2.48	2.55	2.61	2.68	2.74	2.80	2.86	2.92	2.98	3.04	3.09	3.15	3.20	3.25
	70	1.72	1.80	1.88	1.96	2.03	2.10	2.17	2.24	2.30	2.37	2.43	2.49	2.54	2.60	2.66	2.72	2.77	2.82	2.87	2.92	2.97	3.02
	80	1.61	1.69	1.77	1.84	1.91	1.98	2.04	2.11	2.17	2.23	2.28	2.34	2.39	2.45	2.50	2.55	2.60	2.65	2.70	2.75	2.80	2.85
	90	1.53	1.60	1.67	1.74	1.81	1.87	1.93	1.99	2.05	2.10	2.16	2.21	2.26	2.31	2.37	2.42	2.46	2.51	2.56	2.61	2.65	2.69
	100	1.46	1.53	1.60	1.67	1.73	1.79	1.84	1.90	1.96	2.01	2.06	2.11	2.16	2.21	2.26	2.31	2.35	2.40	2.44	2.49	2.53	2.57
	110	1.39	1.46	1.52	1.58	1.64	1.70	1.76	1.81	1.86	1.91	1.96	2.01	2.06	2.11	2.15	2.20	2.24	2.28	2.32	2.37	2.41	2.45
	120	1.33	1.40	1.46	1.52	1.58	1.64	1.69	1.74	1.79	1.84	1.88	1.93	1.98	2.02	2.06	2.11	2.15	2.19	2.23	2.27	2.31	2.35
	130	1.29	1.35	1.41	1.47	1.53	1.58	1.63	1.68	1.73	1.78	1.82	1.87	1.91	1.96	2.00	2.04	2.08	2.12	2.16	2.20	2.23	2.27
	140	1.25	1.31	1.36	1.42	1.47	1.53	1.58	1.62	1.67	1.72	1.76	1.80	1.85	1.89	1.93	1.97	2.01	2.05	2.08	2.12	2.16	2.19
10	60	3.23	3.38	3.54	3.69	3.82	3.96	4.09	4.21	4.34	4.45	4.57	4.68	4.79	4.90	5.01	5.11	5.21	5.31	5.41	5.50	5.60	5.69
	70	3.01	3.16	3.30	3.43	3.56	3.69	3.81	3.92	4.04	4.15	4.26	4.36	4.47	4.57	4.67	4.76	4.86	4.95	5.04	5.13	5.22	5.30
	80	2.84	2.97	3.11	3.23	3.36	3.47	3.59	3.70	3.80	3.91	4.01	4.11	4.21	4.30	4.39	4.48	4.57	4.66	4.75	4.83	4.91	4.99
	90	2.73	2.86	2.99	3.11	3.23	3.34	3.45	3.56	3.66	3.76	3.86	3.95	4.05	4.14	4.23	4.32	4.40	4.48	4.57	4.65	4.73	4.81
	100	2.53	2.65	2.77	2.88	2.99	3.09	3.20	3.29	3.39	3.48	3.57	3.66	3.75	3.83	3.91	3.99	4.07	4.15	4.23	4.30	4.38	4.45
	110	2.48	2.60	2.71	2.83	2.93	3.04	3.14	3.23	3.33	3.42	3.50	3.59	3.68	3.76	3.84	3.92	4.00	4.07	4.15	4.22	4.29	4.36
	120	2.36	2.47	2.58	2.68	2.79	2.88	2.98	3.07	3.16	3.24	3.33	3.41	3.49	3.57	3.65	3.72	3.80	3.87	3.94	4.01	4.08	4.14
	130	2.27	2.38	2.48	2.59	2.68	2.78	2.88	2.96	3.04	3.13	3.21	3.29	3.36	3.44	3.51	3.59	3.66	3.73	3.79	3.86	3.93	3.99
	140	2.19	2.30	2.40	2.50	2.60	2.68	2.77	2.85	2.94	3.02	3.10	3.17	3.25	3.32	3.39	3.46	3.53	3.60	3.66	3.73	3.79	3.86

(ORIFICE FLOW CONDITION)

Diameter Barrel	Head in Feet 4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0	10.5	11.0
6"	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.7
8"	3.2	3.3	3.5	3.7	3.9	4.0	4.2	4.3	4.5	4.6	4.7	4.9	5.0	5.1	5.2
10"	5.3	5.6	5.9	6.2	6.5	6.8	7.0	7.3	7.5	7.8	8.0	8.2	8.4	8.6	8.8

(WEIR FLOW CONDITION)

Diameter Riser	Head in Feet 0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
12"	2.2	3.0	4.0	5.0	6.1	7.3	8.6	9.9	11.2	12.7	14.2	15.7	17.3	18.9	20.6
18"	3.3	4.5	6.0	7.5	9.2	11.0	12.8	14.8	16.9	19.0	21.3	23.6	26.0	28.5	31.0
21"	3.8	5.3	7.0	8.8	10.7	12.8	15.0	17.3	19.7	22.2	24.8	27.5	30.3	33.2	36.2

0504-SCS-LINCOLN, NEBR. 1958

Figure 16.35-1

HEAD DISCHARGE TABLE FOR SMALL CORRUGATED METAL PIPE DROP INLETS USED AS TRICKLE TUBES
(FULL PIPE FLOW CONDITIONS)

BARREL Diam. In.	Length Feet	Head in Feet 16.0	16.5	17.0	17.5	18.0	18.5	19.0	19.5	20.0	20.5	21.0	21.5	22.0	22.5	23.0	23.5	24.0	24.5	25.0	25.5	26.0	26.5
	60	1.59	1.61	1.63	1.66	1.68	1.70	1.73	1.75	1.77	1.79	1.82	1.84	1.86	1.88	1.90	1.92	1.94	1.96	1.98	2.00	2.02	2.04
	70	1.48	1.50	1.52	1.55	1.57	1.59	1.61	1.63	1.65	1.67	1.69	1.71	1.73	1.75	1.77	1.79	1.81	1.83	1.85	1.87	1.89	1.90
	80	1.39	1.41	1.43	1.45	1.47	1.49	1.51	1.53	1.55	1.57	1.59	1.61	1.63	1.65	1.66	1.68	1.70	1.72	1.73	1.75	1.77	1.79
	90	1.31	1.33	1.35	1.37	1.39	1.41	1.43	1.45	1.47	1.49	1.50	1.52	1.54	1.56	1.57	1.59	1.61	1.62	1.64	1.66	1.67	1.69
6	100	1.25	1.27	1.29	1.30	1.32	1.34	1.36	1.38	1.39	1.41	1.43	1.45	1.46	1.48	1.50	1.51	1.53	1.54	1.56	1.58	1.59	1.61
	110	1.19	1.21	1.23	1.25	1.27	1.28	1.30	1.31	1.33	1.35	1.37	1.38	1.40	1.42	1.43	1.45	1.46	1.48	1.49	1.51	1.52	1.54
	120	1.14	1.16	1.18	1.19	1.21	1.23	1.24	1.26	1.28	1.29	1.31	1.32	1.34	1.35	1.37	1.38	1.40	1.41	1.43	1.44	1.46	1.47
	130	1.10	1.12	1.14	1.15	1.17	1.19	1.20	1.22	1.23	1.25	1.26	1.28	1.29	1.31	1.32	1.34	1.35	1.37	1.38	1.39	1.41	1.42
	140	1.06	1.08	1.10	1.11	1.13	1.14	1.16	1.17	1.19	1.20	1.22	1.23	1.25	1.26	1.27	1.29	1.30	1.31	1.33	1.34	1.35	1.37
	60	3.31	3.36	3.41	3.46	3.51	3.55	3.60	3.65	3.70	3.74	3.79	3.83	3.88	3.92	3.96	4.00	4.05	4.09	4.13	4.17	4.21	4.25
	70	3.07	3.12	3.16	3.21	3.25	3.30	3.34	3.39	3.43	3.48	3.52	3.56	3.60	3.64	3.68	3.72	3.76	3.80	3.84	3.87	3.91	3.94
	80	2.89	2.94	2.98	3.02	3.06	3.11	3.15	3.19	3.23	3.27	3.31	3.35	3.39	3.43	3.46	3.50	3.54	3.58	3.61	3.65	3.68	3.71
	90	2.73	2.78	2.82	2.86	2.90	2.94	2.98	3.02	3.05	3.09	3.13	3.17	3.20	3.24	3.28	3.32	3.35	3.39	3.42	3.45	3.48	3.51
8	100	2.61	2.65	2.69	2.73	2.77	2.81	2.84	2.88	2.92	2.96	2.99	3.03	3.06	3.10	3.13	3.16	3.19	3.23	3.26	3.29	3.32	3.35
	110	2.48	2.52	2.56	2.60	2.63	2.67	2.71	2.75	2.78	2.82	2.85	2.88	2.91	2.95	2.98	3.01	3.04	3.08	3.11	3.14	3.17	3.20
	120	2.38	2.42	2.46	2.50	2.53	2.57	2.60	2.64	2.67	2.70	2.73	2.77	2.80	2.83	2.86	2.89	2.92	2.95	2.98	3.01	3.04	3.07
	130	2.31	2.35	2.38	2.42	2.45	2.49	2.52	2.55	2.58	2.61	2.64	2.68	2.71	2.74	2.77	2.80	2.83	2.86	2.89	2.92	2.94	2.95
	140	2.22	2.25	2.28	2.32	2.35	2.38	2.41	2.45	2.48	2.51	2.54	2.57	2.60	2.63	2.66	2.69	2.71	2.74	2.77	2.80	2.82	2.84
	60	5.78	5.87	5.96	6.05	6.13	6.22	6.30	6.38	6.46	6.54	6.62	6.70	6.78	6.86	6.93	7.00	7.08	7.15	7.23	7.30	7.37	7.44
	70	5.39	5.47	5.55	5.63	5.71	5.79	5.87	5.95	6.02	6.10	6.17	6.25	6.32	6.39	6.46	6.53	6.60	6.67	6.73	6.80	6.87	6.93
	80	5.07	5.15	5.23	5.30	5.38	5.45	5.53	5.60	5.67	5.74	5.81	5.88	5.95	6.02	6.08	6.15	6.21	6.28	6.23	6.40	6.47	6.53
	90	4.88	4.96	5.03	5.11	5.18	5.25	5.32	5.39	5.46	5.53	5.59	5.66	5.72	5.79	5.85	5.92	5.98	6.04	6.10	6.16	6.22	6.28
10	100	4.52	4.59	4.66	4.73	4.79	4.86	4.92	4.99	5.05	5.12	5.18	5.24	5.30	5.36	5.42	5.48	5.53	5.59	5.65	5.71	5.76	5.81
	110	4.43	4.50	4.57	4.64	4.70	4.77	4.83	4.90	4.96	5.02	5.08	5.14	5.20	5.26	5.32	5.37	5.43	5.49	5.54	5.60	5.65	5.71
	120	4.21	4.28	4.34	4.40	4.47	4.53	4.59	4.65	4.71	4.77	4.82	4.88	4.94	4.99	5.05	5.10	5.16	5.21	5.26	5.32	5.37	5.42
	130	4.06	4.12	4.18	4.24	4.30	4.36	4.42	4.48	4.53	4.59	4.65	4.70	4.76	4.81	4.86	4.92	4.97	5.02	5.07	5.12	5.17	5.22
	140	3.92	3.98	4.04	4.10	4.16	4.21	4.27	4.32	4.38	4.43	4.49	4.54	4.59	4.64	4.70	4.75	4.80	4.85	4.90	4.95	4.99	5.04

(ORIFICE FLOW CONDITION)

Diameter Barrel	Head in Feet 12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0	21.0	22.0	23.0	24.0	25.0	26.0
6"	2.8	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.2
8"	5.5	5.7	5.9	6.1	6.3	6.5	6 7	6.9	7.1	7.2	7.4	7.6	7.7	7.9	8.1
10"	9.2	9.6	9.9	10.3	10.6	11.0	11.3	11.6	11.9	12.2	12.5	12.7	13.0	13.3	13.6

(WEIR FLOW CONDITION)

Diameter Riser	Head in Feet 2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8
12"	24.2	27.9	31.8	35.9	40.1	44.5	49.0	54.0	58.0	63.0	68.0	74.0	79.0	84.0	90.1
18"	36.3	41.9	47.7	53.8	60.2	66.7	73.5	80.5	87.7	95.1	102.7	110.5	118.5	126.7	135.1
21"	42.4	48.9	55.7	62.8	70.2	77.8	85.8	93.9	102.3	111.0	119.8	128.9	138.3	147.8	157.6

Figure 16.35-2

59M-112-2(2)

5. PIPE FLOW (CONT'D)

Closed Conduit Spillways (cont'd)

Example of Drop Inlet Flow Determination (cont'd)

Given: A reservoir in which the maximum water surface elevation cannot exceed 95.0. The riser of a drop inlet is to be based at elevation 76.0 and the invert at the outlet end of the barrel is to be 20.0 feet below the water surface. The drop inlet spillway must discharge an inflow Q of 49 c.f.s., under these conditions.

Problem: Determine the correct diameter of CMP riser pipe and CMP barrel such that the barrel will flow full.
Determine the maximum elevation for the crest of the riser.

Solution: By trial, select the following pipe diameters:

$$D_1 = 24 \text{ inches}$$
$$D_2 = 1.5 \times D_1 = 36 \text{ inches}$$

Then: $H_1 = 19$ ft. $H = 18$ ft.

From Figure 16.34-2, a 24-inch CMP, 80 feet long flowing full under a head of 19 feet will discharge 49.4 c.f.s.

From Figure 16.32, a head of 1.6 feet over the 36-inch diameter riser pipe will discharge 51.9 c.f.s., under weir flow conditions.

From Figure 16.33, a head H of 18 feet at the entrance to the barrel will discharge 78.0 c.f.s., under orifice control at that point. Also, Figure 16.33 shows that horizontal orifice control at the crest of the 36-inch riser under a head of 1.6 feet does not govern discharge.

It is obvious that barrel capacity is the lesser and controlling quantity and meets the requirement of the problem, therefore, the assumption of pipe diameters is satisfactory.

It is also evident that by use of the specified pipe diameters, the crest of the riser can be placed at 1.6 feet below the controlling water surface elevation 95.0. This places the elevation of the riser crest at elevation 93.4.

It will be noted in Figures 16.32 and 16.33 that had a D_2/D_1 ratio of 1.25 been tried, a riser diameter of 30 inches would have resulted in orifice control at the crest of the riser and would have necessitated lowering the crest 3.0 below the controlling water surface in order for such orifice control to permit a flow of 49.7 c.f.s. This would result in a crest elevation of 92.0.

5. PIPE FLOW (CONT'D)

Closed Conduit Spillways (cont'd)

The Hood Inlet. This type of inlet is adapted to closed conduit spillways consisting of an inclined pipe extending through an embankment. The inlet is formed by cutting a pipe at an angle. The long side is placed on top and figuratively forms a hood over the entrance. An anti-vortex wall located along the pipe center line, a trash rack, and provision for scour prevention completes the inlet structure. Figure 16.36 is a simplified hood inlet for a closed conduit spillway.

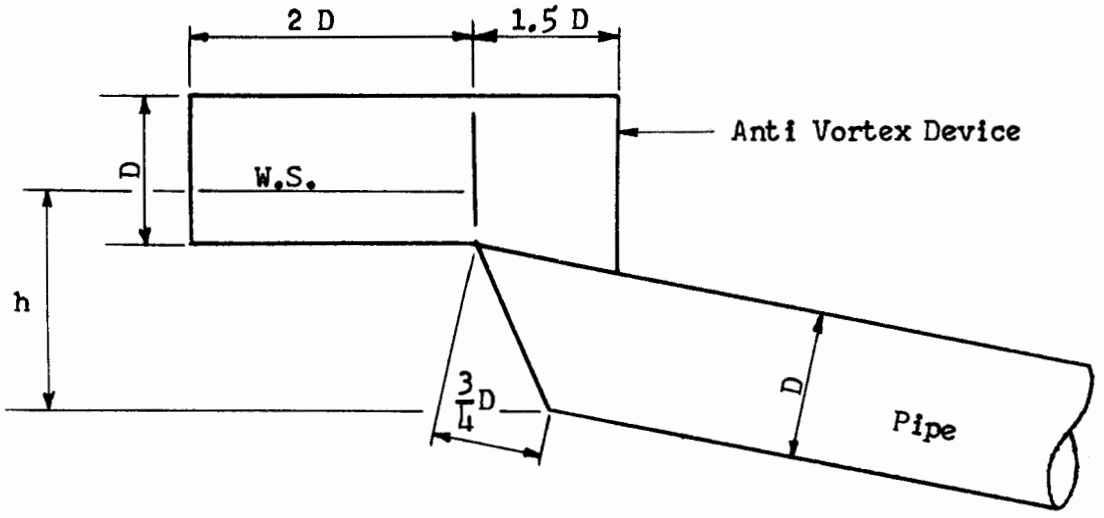

Figure 16.36

The hood inlet has excellent hydraulic characteristics, in that full pipe flow conditions will result with relatively low heads above the top of the pipe.

Weir flow will occur when "h" in Figure 16.36 is less than 1.1 D. Full pipe flow will start when h/D is about 1.4.

The slope of the conduit must be greater than the required friction slope to function at full capacity.

The maximum slope upon which the conduit is placed should not exceed 36 percent.

Scour is a problem at the inlet of the conduit and the embankment area surrounding the invert must be protected if a scour hole is not permissible. The radius of scour holes are determined by the following equation:

5. PIPE FLOW (CONT'D)

Closed Conduit Spillways (cont'd)

The Hood Inlet (cont'd)

$$R = D\left(0.15 + 0.04 \frac{Q}{D^{5/2}}\right) \left(\frac{D}{0.00164}\right)^{1/5}$$

Q = Discharge c.f.s.

where R = Radius in feet of the scour hole

D = Diameter of the pipe, feet

Grain size = 0.5 m.m. = .00164 feet

and

$$S = \frac{Q}{20\ D^{3/2}} - 0.00164 - 0.075\ D$$

where Q = Discharge, c.f.s.

D = Diameter of pipe, feet

S = Depth of scour hole in cohesion-less material, feet

If the scour area is to be protected with riprap, the mean diameter of rock to be used is twice the value of "d" determined by the following equation:

$$d_o = \frac{Q}{20\ D^{3/2}} - 0.075\ D$$

where d_o = grain size, feet for S = 0

D = Diameter of pipe, feet

Q = Discharge, c.f.s.

Figure 16.37 gives minimum diameter of riprap and radius of scour hole if riprap is not used for various pipe diameters and quantities of flow.

Concrete paving over an area of 2 R is the most effective means of preventing a scour hole. On small pipe diameters, the hood inlet can be extended into the pool for prevention of scour if ice in the pool is not a problem. Such extension should be sufficient to provide a water depth below the invert of the pipe at least equal to the anticipated scour hole depth "S" given in the preceding equations.

A simple trash guard for farm ponds is necessary. For larger installations, trash guards of special design are required.

The recommended minimum proportions of hood inlet anti-vortex device are given in Figure 16.36. In farm pond installations where pipe diameters are not usually large, the anti-vortex fin can be made of sheet metal. On larger installations the size of fin becomes a problem requiring special design.

RADIUS OF SCOUR HOLE (R) AND DIAMETER OF RIPRAP (d) FOR STRUCTURES WITH HOOD INLETS ON WELDED STEEL PIPE OR CORRUGATED METAL PIPE

R = Radius of scour hole in cohesionless material in feet

Based on formula: $R = D(0.15 + 0.04\, Q/D^{5/2})\ (D/.00164)^{1/5}$

D = Diameter of pipe in feet

d = Minimum riprap diameter in inches

Based on formula: $d = (Q/20D^{5/2} - 0.075\, D)24$

Q = Discharge in c.f.s.

PIPE DIAMETER IN INCHES																																
6			8			10			12			14			15			16			18			21			24			30		
Q	d	R	Q	d	R	Q	d	R	Q	d	R	Q	d	R	Q	d	R	Q	d	R	Q	d	R	Q	d	R	Q	d	R	Q	d	R
0.50	0.8	0.41	0.75	0.4	0.51	1.50	0.9	0.71	2.50	1.2	0.90	7.00	4.5	1.48	5.00	2.0	1.25	9.00	4.6	1.66	6.00	1.2	1.39	10.00	2.0	1.75	16.00	3.2	2.18	20.00	1.6	2.50
0.75	1.6	0.50	1.00	1.0	0.57	1.75	1.3	0.75	3.50	2.4	1.05	8.00	5.5	1.59	6.00	2.9	1.35	10.00	5.4	1.76	8.00	2.5	1.56	12.00	3.1	1.89	19.00	4.5	2.35	25.00	3.1	2.72
1.00	2.5	0.59	1.25	1.5	0.64	2.00	1.7	0.80	4.50	3.6	1.19	9.00	6.4	1.71	7.00	3.8	1.46	11.00	6.2	1.86	10.00	3.8	1.73	14.00	4.1	2.03	22.00	5.7	2.53	30.00	4.6	2.94
1.25	3.3	0.68	1.50	2.1	0.70	2.25	2.1	0.84	5.50	4.8	1.34	10.00	7.4	1.83	8.00	4.6	1.57	12.00	7.0	1.96	12.00	5.1	1.90	16.00	5.1	2.17	25.00	7.0	2.71	35.00	6.1	3.16
1.50	4.2	0.77	1.75	2.6	0.76	2.50	2.5	0.89	6.50	6.0	1.48	11.00	8.3	1.95	9.00	5.5	1.68	13.00	7.8	2.06	14.00	6.4	2.07	18.00	6.2	2.31	28.00	8.3	2.88	40.00	7.6	3.38
1.75	5.0	0.86	2.00	3.2	0.82	2.75	2.9	0.94	7.50	7.2	1.62	12.00	9.3	2.06	10.00	6.3	1.79	14.00	8.6	2.16	16.00	7.8	2.24	20.00	7.2	2.45	31.00	9.6	3.06	45.00	9.2	3.60
2.00	5.9	0.95	2.25	3.7	0.88	3.00	3.2	0.98	8.50	8.4	1.77	13.00	10.2	2.18	11.00	7.2	1.89	15.00	9.3	2.26	18.00	9.0	2.41	22.00	8.3	2.59	34.00	10.8	3.23	50.00	10.7	3.82
2.25	6.7	1.03	2.50	4.3	0.94	3.25	3.6	1.03	9.50	9.6	1.91	14.00	11.2	2.30	12.00	8.0	2.00	16.00	10.1	2.36	20.00	10.4	2.58	24.00	9.3	2.73	37.00	12.1	3.41	55.00	12.2	4.04
2.50	7.6	1.12	2.75	4.8	1.00	3.50	4.1	1.07	10.50	10.8	2.06	15.00	12.1	2.42	13.00	8.9	2.11	17.00	10.9	2.46	22.00	11.7	2.75	26.00	10.3	2.87	40.00	13.4	3.58	60.00	13.7	4.26
			3.00	5.4	1.06	3.75	4.4	1.12	11.50	12.0	2.20	16.00	13.1	2.53	14.00	9.8	2.22	18.00	11.7	2.56	24.00	13.0	2.93	28.00	11.4	3.01	43.00	14.6	3.76	65.00	15.2	4.47
			3.25	5.9	1.12	4.00	4.8	1.17	12.50	13.2	2.35	17.00	14.0	2.65	15.00	10.6	2.32	19.00	12.5	2.66	26.00	14.3	3.10	30.00	12.4	3.15	46.00	15.9	3.94	70.00	16.7	4.69
			3.50	6.5	1.18	4.25	5.2	1.21	13.50	14.4	2.49	18.00	15.0	2.77	16.00	11.5	2.43	20.00	13.3	2.76	28.00	15.6	3.27	32.00	13.4	3.29	49.00	17.2	4.11	75.00	18.3	4.91
						4.50	5.6	1.26	14.50	15.6	2.64	19.00	15.9	2.89	17.00	12.3	2.54	21.00	14.0	2.86	30.00	16.9	3.44	34.00	14.5	3.42	52.00	18.5	4.29	80.00	19.8	5.13
						4.75	6.0	1.30	15.50	16.8	2.78	20.00	16.9	3.00	18.00	13.2	2.65	22.00	14.8	2.96	32.00	18.2	3.61	36.00	15.5	3.56	55.00	19.7	4.46	85.00	21.3	5.35
						5.00	6.4	1.35	16.50	18.0	2.92	21.00	17.8	3.12	19.00	14.1	2.76	23.00	15.6	3.06	34.00	19.5	3.78	38.00	16.5	3.70	58.00	21.0	4.64	90.00	22.8	5.57
						5.25	6.8	1.40	17.50	19.2	3.07	22.00	18.8	3.24	20.00	14.9	2.86	24.00	16.4	3.16	36.00	20.8	3.95	40.00	17.6	3.84	61.00	22.3	4.81	95.00	24.3	5.79
						5.50	7.2	1.44	18.50	20.4	3.21	23.00	19.7	3.36				25.00	17.2	3.26	38.00	22.1	4.12	42.00	18.6	3.98	64.00	23.5	4.99	100.00	25.9	6.01
						5.75	7.6	1.49				24.00	20.7	3.47				26.00	17.9	3.36	40.00	23.4	4.29	44.00	19.6	4.12	67.00	24.8	5.17	105.00	27.4	6.23
						6.00	8.0	1.53				25.00	21.6	3.59				27.00	18.7	3.46				46.00	20.7	4.26	70.00	26.1	5.34	110.00	28.9	6.45
																		28.00	19.5	3.56				48.00	21.7	4.40	73.00	27.4	5.52	115.00	30.4	6.67
																		29.00	20.3	3.66				50.00	22.8	4.54	76.00	28.6	5.69	120.00	31.9	6.88

Figure 16.37

5. PIPE FLOW (CONT'D)

Closed Conduit Spillways (cont'd)

The Hood Inlet (cont'd)

The capacity of hood inlet pipes under various heads and length of pipe are given on Figure 16.39 which covers corrugated metal pipe. Figure 16.40 covers welded steel pipe.

The values in Figure 16.39 and 16.40 were derived from the formula:

$$Q = a\sqrt{\frac{2\,g\,H}{1 + K_e + K_m + K_p\,L}}$$

Where H = total available head, ft.
g = acceleration of gravity 32.16 ft/sec^2
K_e = entrance loss coefficient
K_m = miterbend loss coefficient
K_p = pipe-friction loss coefficient (Page 15, T. R. #3)
Q = discharge (cfs)
a = cross sectional area of culvert, ft^2
L = length of conduit, ft.
h = pipe invert to crest of emergency spillway

Values of S_n (neutral slope) are not shown in the tables.
Values of Q (cfs) in the tables reflect slopes equal to or greater than S_n.

$$S_n = K_p \left(\frac{V_2}{2g}\right)$$

When using these tables, it must be remembered that for a certain length of pipe with a certain head and a certain amount of Q (cfs) the pipe will have a minimum S_n in order to make the pipe flow full. Discharges that would cause the pipe to have an S of 36% or greater were eliminated.

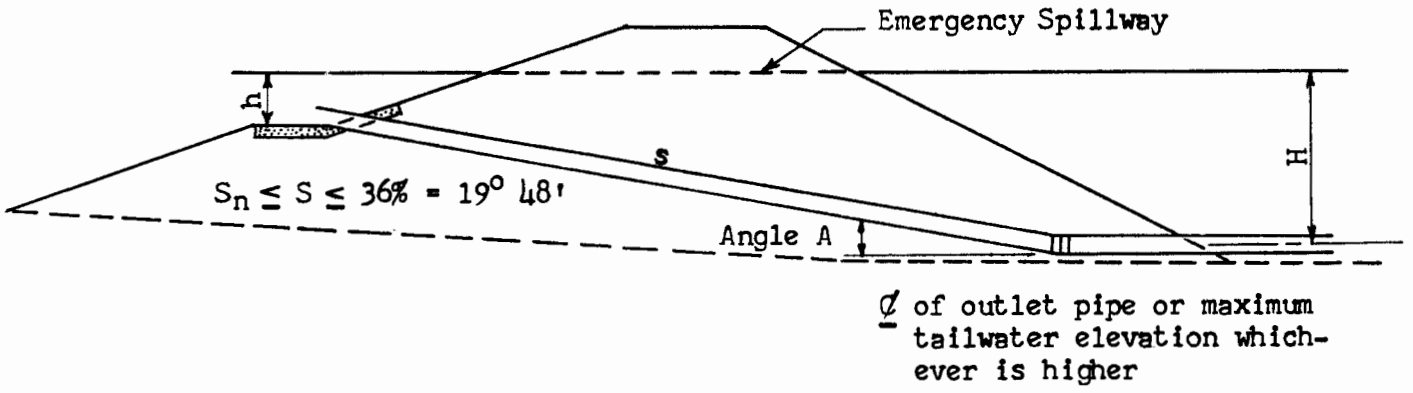

Figure 16.38

HEAD DISCHARGE TABLES FOR CORRUGATED METAL HOOD INLETS
FULL PIPE FLOW CONDITIONS
(For Irrigation)

HEAD IN FEET		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Barrel		(Discharge in cfs)										
Dia.	Length											
8"	10	1.40	1.72	1.98	2.21	2.42	2.62	2.80	2.97	3.13	3.28	3.43
	12	1.34	1.64	1.89	2.12	2.32	2.50	2.68	2.84	3.00	3.14	3.28
	14	1.28	1.57	1.81	2.02	2.22	2.39	2.56	2.71	2.86	3.00	3.13
	16	1.23	1.51	1.74	1.94	2.13	2.30	2.46	2.61	2.75	2.88	3.01
	18	1.18	1.45	1.67	1.87	2.04	2.21	2.36	2.50	2.64	2.77	2.89
	20	1.14	1.40	1.61	1.80	1.97	2.13	2.28	2.42	2.55	2.67	2.79
	22	1.11	1.36	1.57	1.75	1.91	2.08	2.22	2.35	2.48	2.60	2.72
	24	1.07	1.31	1.51	1.69	1.85	2.00	2.14	2.27	2.39	2.51	2.62
	26	1.05	1.29	1.48	1.66	1.82	1.96	2.10	2.23	2.35	2.46	2.57
	28	1.02	1.25	1.44	1.61	1.77	1.91	2.04	2.16	2.28	2.39	2.50
	30	.99	1.21	1.40	1.57	1.71	1.85	1.98	2.10	2.21	2.32	2.42
	32	.97	1.19	1.37	1.53	1.68	1.81	1.94	2.06	2.17	2.27	2.38
	34	.94	1.15	1.33	1.49	1.63	1.76	1.88	1.99	2.10	2.20	2.30
	36	.93	1.14	1.32	1.47	1.61	1.74	1.86	1.97	2.08	2.18	2.28
	38	.90	1.10	1.27	1.42	1.56	1.68	1.80	1.91	2.01	2.11	2.20
10"	10	2.34	2.87	3.31	3.70	4.06	4.38	4.69	4.97	5.24	5.49	5.74
	12	2.25	2.75	3.18	3.55	3.89	4.21	4.50	4.77	5.03	5.27	5.51
	14	2.17	2.65	3.06	3.42	3.75	4.05	4.33	4.59	4.84	5.08	5.30
	16	2.09	2.56	2.96	3.31	3.62	3.91	4.18	4.44	4.68	4.90	5.12
	18	2.03	2.48	2.86	3.20	3.51	3.79	4.05	4.30	4.53	4.75	4.96
	20	1.96	2.40	2.77	3.10	3.40	3.67	3.92	4.16	4.39	4.60	4.80
	22	1.91	2.33	2.69	3.01	3.30	3.56	3.81	4.04	4.26	4.47	4.67
	24	1.85	2.27	2.62	2.93	3.21	3.47	3.71	3.93	4.15	4.35	4.54
	26	1.81	2.21	2.56	2.86	3.13	3.38	3.61	3.83	4.04	4.24	4.43
	28	1.76	2.16	2.49	2.79	3.05	3.30	3.53	3.74	3.94	4.13	4.32
	30	1.72	2.11	2.43	2.72	2.98	3.22	3.44	3.65	3.85	4.04	4.22
	32	1.68	2.06	2.38	2.64	2.91	3.15	3.36	3.57	3.76	3.94	4.12
	34	1.65	2.02	2.33	2.61	2.85	3.08	3.30	3.50	3.68	3.86	4.04
	36	1.61	1.98	2.28	2.55	2.80	3.02	3.23	3.42	3.61	3.78	3.95
	38	1.58	1.94	2.24	2.50	2.74	2.96	3.17	3.36	3.54	3.71	3.88
12"	10	3.55	4.35	5.02	5.61	6.15	6.64	7.10	7.53	7.94	8.32	8.69
	12	3.41	4.18	4.82	5.39	5.91	6.38	6.82	7.23	7.62	8.00	8.35
	14	3.31	4.05	4.68	5.23	5.73	6.19	6.62	7.02	7.40	7.76	8.11
	16	3.21	3.93	4.54	5.08	5.56	6.00	6.42	6.80	7.18	7.53	7.86
	18	3.12	3.82	4.41	4.93	5.40	5.83	6.24	6.62	6.98	7.32	7.64
	20	3.03	3.71	4.28	4.79	5.24	5.70	6.06	6.43	6.78	7.11	7.42
	22	2.96	3.63	4.19	4.68	5.13	5.54	5.92	6.28	6.62	6.94	7.25
	24	2.89	3.54	4.09	4.57	5.00	5.41	5.78	6.13	6.46	6.78	7.08
	26	2.82	3.45	3.99	4.46	4.88	5.28	5.64	5.98	6.31	6.61	6.91
	28	2.76	3.38	3.90	4.36	4.78	5.16	5.52	5.85	6.17	6.47	6.76
	30	2.70	3.31	3.81	4.27	4.68	5.05	5.40	5.73	6.04	6.33	6.61
	32	2.64	3.23	3.73	4.17	4.57	4.94	5.28	5.60	5.90	6.19	6.47
	34	2.58	3.16	3.65	4.08	4.47	4.83	5.16	5.47	5.77	6.05	6.32
	36	2.53	3.10	3.58	4.00	4.38	4.73	5.06	5.37	5.66	5.93	6.20
	38	2.50	3.06	3.54	3.95	4.33	4.68	5.00	5.30	5.59	5.86	6.12

Weir Flow Controls; "h" less than 1.4D

Diameter = 8",				Diameter = 10"				Diameter = 12"			
h	Q	h	Q	h	Q	h	Q	h	Q	h	Q
.13	.06	.54	.57	.17	.10	.66	.98	.20	.16	.80	1.56
.27	.17	.67	.81	.33	.29	.83	1.38	.40	.46	1.00	2.20
.40	.32	.74	.92	.50	.55	.91	1.57	.60	.88	1.10	2.50

Figure 16.39-1

HEAD DISCHARGE TABLES FOR CORRUGATED METAL PIPE HOOD INLETS
FULL PIPE FLOW CONDITIONS
(For Dams)

HEAD IN FEET		4	6	8	10	12	14	16	18	20	22	24	26	28	30
Barrel Dia.	Length	Q (Discharge in cfs)													
12"	40	4.88	5.98	6.90	7.72	8.45	9.13	9.76	10.4	10.9	11.4	-	-	-	-
	50	4.52	5.53	6.39	7.15	7.83	8.46	9.04	9.59	10.1	10.6	11.1	11.5	-	-
	60	4.20	5.14	5.94	6.64	7.27	7.86	8.40	8.91	9.40	9.85	10.3	10.7	11.1	11.5
	70	3.96	4.85	5.60	6.26	6.86	7.41	7.92	8.40	8.85	9.29	9.70	10.1	10.5	10.8
	80	3.76	4.60	5.32	5.94	6.51	7.03	7.52	7.98	8.41	8.82	9.21	9.59	9.95	10.3
	90	3.58	4.38	5.06	5.66	6.20	6.70	7.16	7.59	8.00	8.40	8.77	9.13	9.47	9.80
	100	3.42	4.19	4.84	5.41	5.92	6.40	6.84	7.26	7.65	8.02	8.38	8.72	9.05	9.37
	110	3.28	4.02	4.64	5.19	5.68	6.14	6.56	6.96	7.33	7.69	8.03	8.36	8.68	8.98
	120	3.16	3.87	4.47	5.00	5.47	5.91	6.32	6.70	7.07	7.41	7.74	8.06	8.36	8.65
	130	3.04	3.72	4.30	4.81	5.27	5.69	6.08	6.45	6.80	7.13	7.45	7.75	8.04	8.33
	140	2.96	3.62	4.19	4.68	5.13	5.54	5.92	6.28	6.62	6.94	7.25	7.55	7.83	8.11
	150	2.86	3.50	4.04	4.52	4.95	5.35	5.72	6.07	6.39	6.71	7.01	7.29	7.57	7.83
	160	2.78	3.40	3.93	4.40	4.81	5.20	5.56	5.90	6.22	6.52	6.81	7.09	7.36	7.61
15"	40	8.46	10.4	12.0	13.4	14.7	15.8	16.9	17.9	18.9	19.8	-	-	-	-
	50	7.86	9.62	11.1	12.4	13.6	14.7	15.7	16.7	17.6	18.4	19.3	20.0	-	-
	60	7.38	9.03	10.4	11.7	12.8	13.8	14.8	15.7	16.5	17.3	18.1	18.8	19.5	-
	70	6.97	8.53	9.85	11.0	12.1	13.0	13.9	14.8	15.6	16.3	17.1	17.8	18.5	19.1
	80	6.62	8.11	9.36	10.5	11.5	12.4	13.2	14.0	14.8	15.5	16.2	16.9	17.5	18.1
	90	6.32	7.74	8.94	10.0	11.0	11.8	12.6	13.4	14.1	14.8	15.5	16.1	16.7	17.3
	100	6.06	7.42	8.57	9.60	10.5	11.3	12.1	12.9	13.6	14.3	14.9	15.5	16.0	16.6
	110	5.83	7.14	8.24	9.20	10.1	10.9	11.7	12.4	13.0	13.7	14.3	14.9	15.4	16.0
	120	5.62	6.88	7.95	8.89	9.74	10.5	11.2	11.9	12.6	13.2	13.8	14.3	14.9	15.4
	130	5.43	6.65	7.68	8.59	9.41	10.2	10.9	11.3	12.2	12.7	13.3	13.9	14.4	15.0
	140	5.26	6.45	7.44	8.32	9.12	9.85	10.5	11.2	11.8	12.3	12.9	13.4	13.9	14.4
	150	5.11	6.26	7.23	8.08	8.85	9.56	10.2	10.9	11.4	12.0	12.5	13.0	13.5	14.0
	160	4.97	6.09	7.03	7.86	8.61	9.30	9.94	10.5	11.1	11.7	12.2	12.7	13.2	13.6
18"	40	13.1	16.0	18.5	20.7	22.7	24.5	26.2	27.8	29.3	30.7	32.1	-	-	-
	50	12.2	15.0	17.3	19.4	21.2	22.9	24.5	26.0	27.4	28.7	30.0	31.2	32.4	-
	60	11.5	14.1	16.3	18.3	20.0	21.6	23.1	24.5	25.8	27.1	28.3	29.4	30.6	31.6
	70	11.0	13.4	15.5	17.3	19.0	20.5	21.9	23.2	24.5	25.7	26.8	27.9	29.0	30.0
	80	10.4	12.8	14.8	16.5	18.1	19.5	20.9	22.2	23.4	24.5	25.6	26.6	27.6	28.6
	90	10.0	12.3	14.2	15.8	17.3	18.7	20.0	21.2	22.4	23.5	24.5	25.5	26.5	27.4
	100	9.60	11.8	13.6	15.2	16.6	18.0	19.2	20.4	21.5	22.5	23.5	24.5	25.4	26.3
	110	9.25	11.3	13.1	14.6	16.0	17.3	18.5	19.7	20.7	21.7	22.7	23.6	24.5	25.3
	120	8.93	10.9	12.6	14.1	15.5	16.7	17.9	20.0	21.0	21.9	21.9	22.8	23.6	24.5
	130	8.65	10.6	12.2	13.7	15.0	16.2	17.3	18.4	19.3	20.3	21.2	22.1	22.9	23.7
	140	8.39	10.3	11.9	13.3	14.5	15.7	16.8	17.8	18.8	19.7	20.6	21.4	22.2	23.0
	150	8.16	9.99	11.5	12.9	14.1	15.3	16.3	17.3	18.2	19.1	20.0	20.8	21.6	22.3
	160	7.94	9.72	11.2	12.6	13.8	14.9	15.9	16.8	17.8	18.6	19.5	20.3	21.0	21.7

Weir Flow Controls; "H" less than 1.4D

Diameter = 12"				Diameter = 15"				Diameter = 18"			
h	Q	h	Q	h	Q	h	Q	h	Q	h	Q
.20	.16	.80	1.56	.25	.28	1.00	2.73	.30	.44	1.20	4.30
.40	.46	1.00	2.20	.50	.80	1.25	3.84	.60	1.27	1.50	6.06
.60	.88	1.10	2.50	.75	1.54	1.38	4.37	.90	2.43	1.65	6.89

Figure 16.39-2

HEAD DISCHARGE TABLES FOR CORRUGATED METAL PIPE HOOD INLETS
FULL PIPE FLOW CONDITIONS
(For Dams)

HEAD IN FEET		4	6	8	10	12	14	16	18	20	22	24	26	28	30
Barrel Dia.	Barrel Length	Q (Discharge in cfs)													
21"	40	18.8	23.1	26.6	29.8	32.6	35.3	37.7	40.0	42.1	44.2	46.2	48.0		
	50	17.7	21.7	25.1	28.0	30.7	33.2	35.5	37.6	39.7	41.6	43.4	45.2	46.9	48.6
	60	16.8	20.5	23.7	26.5	29.1	31.4	33.5	35.6	37.5	39.3	41.1	42.8	44.4	45.9
	70	16.0	19.6	22.6	25.3	27.7	29.9	31.8	33.7	35.8	37.5	39.2	40.8	42.3	43.8
	80	15.3	18.7	21.6	24.2	26.5	28.6	30.6	32.4	34.2	35.8	37.4	39.0	40.4	41.8
	90	14.7	17.9	20.7	23.2	25.4	27.4	29.3	31.1	32.8	34.4	35.9	37.4	38.8	40.1
	100	14.1	17.3	20.0	22.3	24.5	26.4	28.2	30.0	31.6	33.1	34.6	36.0	37.4	38.7
	110	13.6	16.7	19.3	21.6	23.6	25.5	27.3	28.9	30.5	32.0	33.4	34.8	36.1	37.4
	120	13.2	16.2	18.7	20.9	22.9	24.7	26.4	28.0	29.5	31.0	32.3	33.7	34.9	36.2
	130	12.8	15.6	18.1	20.2	22.1	23.9	25.5	27.1	28.6	30.0	31.3	32.6	33.8	35.0
	140	12.4	15.2	17.6	19.7	21.5	23.3	24.9	26.4	27.8	29.2	30.5	31.7	32.9	34.1
	150	12.1	14.8	17.1	19.1	21.0	22.6	24.2	25.7	27.1	28.4	29.6	30.8	32.0	33.1
	160	11.8	14.4	16.6	18.6	20.4	22.0	23.5	24.9	26.3	27.6	28.8	30.0	31.1	32.2
24"	40	25.7	31.5	36.4	40.7	44.6	48.1	51.4	54.6	57.5	60.3	63.0	65.6	68.1	70.1
	50	24.3	29.8	34.4	38.4	42.1	45.5	48.6	51.6	54.3	57.0	59.5	62.0	64.2	66.6
	60	23.1	28.3	32.7	36.5	40.0	43.2	46.2	49.0	51.7	54.2	56.6	58.9	61.1	63.3
	70	22.0	27.0	31.2	34.8	38.2	41.2	44.1	46.8	49.3	51.7	54.0	56.2	58.2	60.4
	80	21.1	25.8	29.8	33.4	36.5	39.5	42.2	44.8	47.2	49.5	51.7	53.8	55.7	57.8
	90	20.3	24.9	28.8	32.2	35.2	38.1	40.7	43.2	45.5	47.7	49.8	51.9	53.7	55.7
	100	19.6	24.0	27.7	31.0	33.9	36.7	39.2	41.6	43.8	45.9	48.0	50.0	51.8	53.7
	110	19.0	23.2	26.8	30.0	32.8	35.5	37.9	40.2	42.4	44.5	46.5	48.4	50.1	51.9
	120	18.4	22.5	26.0	29.1	31.9	34.4	36.8	39.0	41.1	43.1	45.1	46.9	48.6	50.4
	130	17.8	21.8	25.2	28.2	30.9	33.4	35.7	37.8	39.9	41.8	43.7	45.5	47.1	48.8
	140	17.3	21.2	24.5	27.4	30.0	32.4	34.7	36.8	38.8	40.6	42.5	44.2	45.8	47.5
	150	16.9	20.7	23.9	26.7	29.3	31.6	33.8	35.8	37.8	39.6	41.4	43.1	44.6	46.3
	160	16.5	20.1	23.3	26.0	28.5	30.8	32.9	34.9	36.8	38.6	40.3	41.9	43.5	45.1
30"	40	42.9	52.5	60.7	67.8	74.3	80.3	85.8	91.1	96.0	100.6	105.1	109.4	113.6	117.6
	50	41.0	50.1	57.9	64.7	70.9	76.6	81.9	86.9	91.6	96.0	100.3	104.4	108.4	112.1
	60	39.2	48.0	55.4	61.9	67.9	73.3	78.4	83.1	87.6	91.9	96.0	99.9	103.7	107.3
	70	37.6	46.1	53.2	59.5	65.1	70.4	75.2	79.8	84.1	88.2	92.1	95.9	99.5	103.0
	80	36.2	44.4	51.2	57.3	62.8	67.8	72.4	76.9	81.0	85.0	88.8	92.4	95.9	99.2
	90	35.1	42.9	49.6	55.4	60.7	65.6	70.1	74.4	78.4	82.2	85.9	89.4	92.8	96.0
	100	33.9	41.5	47.9	53.6	58.7	63.4	67.8	71.9	75.8	79.4	83.0	86.4	89.6	92.8
	110	32.8	40.2	46.4	51.9	56.8	61.4	65.6	69.6	73.3	76.9	80.3	83.6	86.8	89.8
	120	31.9	39.1	45.1	50.5	55.3	59.7	63.8	67.7	71.4	74.8	78.2	81.4	84.4	87.4
	130	31.1	38.0	43.9	49.1	53.7	58.1	62.1	65.8	69.4	72.8	76.0	79.1	82.1	85.0
	140	30.2	37.0	42.8	47.8	52.4	56.6	60.5	64.2	67.6	70.9	74.1	77.1	80.0	82.8
	150	29.7	36.3	41.9	46.9	51.4	55.5	59.3	62.9	66.3	69.5	72.6	75.6	78.5	81.2
	160	28.9	35.4	40.8	45.6	50.0	54.0	57.7	61.2	64.6	67.7	70.7	73.6	76.4	79.1

Weir Flow Controls; "h" less than 1.4D

Diameter = 21"				Diameter = 24"				Diameter = 30"			
h	Q	h	Q	h	Q	h	Q	h	Q	h	Q
.35	.60	1.40	6.30	.40	.90	1.60	8.80	.50	1.60	2.00	1.59
.70	1.80	1.75	8.80	.80	2.60	2.00	12.40	1.00	4.70	2.50	22.50
1.05	3.50	1.93	10.00	1.20	5.00	2.30	14.10	1.50	9.00	2.80	25.60

Figure 16.39-3

HEAD DISCHARGE TABLES FOR WELDED STEEL PIPE HOOD INLETS
FULL PIPE FLOW CONDITIONS
(For Irrigation)

HEAD IN FEET		1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
Barrel Dia.	Length	(Discharge in cfs)										
6"	10	0.91	1.12	1.29	1.44	1.58	1.71	1.83	1.94	2.04	2.14	2.24
	12	0.89	1.09	1.26	1.41	1.54	1.67	1.78	1.89	1.99	2.09	2.18
	14	0.87	1.06	1.23	1.37	1.51	1.63	1.74	1.84	1.94	2.04	2.13
	16	0.85	1.04	1.20	1.34	1.47	1.58	1.69	1.79	1.89	1.98	2.07
	18	0.83	1.02	1.18	1.31	1.44	1.55	1.66	1.76	1.86	1.95	2.04
	20	0.82	1.00	1.15	1.29	1.41	1.53	1.63	1.73	1.82	1.91	2.00
	22	0.80	0.98	1.13	1.26	1.39	1.50	1.60	1.70	1.79	1.88	1.96
	24	0.78	0.96	1.10	1.23	1.35	1.46	1.56	1.66	1.75	1.83	1.91
	26	0.77	0.94	1.09	1.22	1.33	1.44	1.54	1.63	1.72	1.81	1.89
	28	0.76	0.93	1.07	1.20	1.31	1.42	1.51	1.61	1.69	1.78	1.85
	30	0.74	0.91	1.05	1.18	1.29	1.39	1.49	1.58	1.66	1.74	1.82
	32	0.73	0.90	1.03	1.16	1.27	1.37	1.46	1.55	1.63	1.71	1.79
	34	0.72	0.88	1.02	1.14	1.25	1.35	1.44	1.53	1.61	1.69	1.76
	36	0.71	0.87	1.00	1.12	1.23	1.33	1.42	1.50	1.58	1.66	1.74
	38	0.70	0.86	0.99	1.11	1.21	1.31	1.40	1.48	1.56	1.64	1.71
8"	10	1.71	2.09	2.42	2.70	2.96	3.20	3.42	3.63	3.82	4.01	4.19
	12	1.68	2.06	2.38	2.66	2.91	3.14	3.36	3.56	3.76	3.94	4.11
	14	1.65	2.02	2.33	2.61	2.86	3.09	3.30	3.50	3.69	3.87	4.04
	16	1.62	1.98	2.29	2.56	2.81	3.03	3.24	3.44	3.62	3.80	3.97
	18	1.60	1.96	2.26	2.53	2.77	2.99	3.20	3.39	3.58	3.75	3.92
	20	1.57	1.92	2.22	2.48	2.72	2.94	3.14	3.34	3.51	3.68	3.84
	22	1.55	1.90	2.19	2.45	2.68	2.90	3.10	3.29	3.47	3.63	3.80
	24	1.53	1.87	2.16	2.42	2.65	2.86	3.06	3.25	3.42	3.59	3.75
	26	1.50	1.84	2.12	2.37	2.60	2.81	3.00	3.18	3.35	3.52	3.67
	28	1.48	1.81	2.09	2.34	2.56	2.77	2.96	3.14	3.31	3.47	3.62
	30	1.46	1.79	2.06	2.31	2.53	2.73	2.92	3.10	3.26	3.42	3.58
	32	1.44	1.76	2.04	2.28	2.49	2.69	2.88	3.05	3.22	3.38	3.53
	34	1.42	1.74	2.01	2.25	2.46	2.66	2.84	3.01	3.18	3.33	3.48
	36	1.41	1.73	1.99	2.23	2.44	2.64	2.82	2.99	3.15	3.31	3.45
	38	1.39	1.70	1.97	2.20	2.41	2.60	2.78	2.95	3.11	3.26	3.40
10"	10	2.76	3.38	3.90	4.36	4.78	5.16	5.52	5.85	6.17	6.47	6.76
	12	2.73	3.34	3.86	4.32	4.73	5.11	5.46	5.79	6.10	6.40	6.69
	14	2.69	3.30	3.80	4.25	4.66	5.03	5.38	5.71	6.01	6.31	6.59
	16	2.66	3.26	3.76	4.20	4.60	4.98	5.32	5.64	5.95	6.24	6.51
	18	2.62	3.21	3.70	4.14	4.54	4.90	5.24	5.56	5.86	6.14	6.42
	20	2.59	3.17	3.66	4.09	4.49	4.85	5.18	5.49	5.79	6.07	6.34
	22	2.55	3.12	3.61	4.03	4.42	4.77	5.10	5.41	5.70	5.98	6.24
	24	2.52	3.09	3.56	3.98	4.36	4.71	5.04	5.34	5.63	5.91	6.17
	26	2.49	3.05	3.52	3.94	4.31	4.66	4.98	5.28	5.57	5.84	6.10
	28	2.47	3.03	3.49	3.91	4.28	4.62	4.94	5.24	5.52	5.79	6.05
	30	2.44	2.99	3.45	3.86	4.23	4.57	4.88	5.18	5.46	5.72	5.98
	32	2.41	2.95	3.41	3.81	4.17	4.51	4.82	5.11	5.39	5.65	5.90
	34	2.38	2.92	3.37	3.76	4.12	4.45	4.76	5.05	5.32	5.58	5.83
	36	2.36	2.89	3.34	3.73	4.09	4.42	4.72	5.01	5.28	5.53	5.78
	38	2.33	2.85	3.29	3.68	4.04	4.36	4.66	4.94	5.21	5.46	5.71

Weir Flow Controls; "h" less than 1.4D

Diameter = 6"				Diameter = 8"				Diameter = 10"			
h	Q	h	Q	h	Q	h	Q	h	Q	h	Q
0.10	0.03	0.40	0.28	0.13	0.06	0.54	0.57	0.17	0.10	0.66	0.98
0.20	0.08	0.50	0.39	0.27	0.17	0.67	0.81	0.33	0.29	0.83	1.38
0.30	0.16	0.55	0.44	0.40	0.32	0.74	0.92	0.50	0.55	0.91	1.57

Figure 16.40-1

HEAD DISCHARGE TABLES FOR WELDED STEEL PIPE HOOD INLETS
FULL PIPE FLOW CONDITIONS
(For Dams)

HEAD IN FEET		4	6	8	10	12	14	16	18	20	22	24	26	28	30
Barrel Dia.	Barrel Length	Q (Discharge in cfs)													
12"	40	6.94	8.50	9.82	11.0	12.0	13.0	13.9	14.7	15.5	16.3	17.0	17.7		
	50	6.66	8.16	9.42	10.5	11.5	12.5	13.3	14.1	14.9	15.6	16.3	17.0	17.6	
	60	6.42	7.86	9.08	10.1	11.1	12.0	12.8	13.6	14.4	15.1	15.7	16.4	17.0	17.6
	70	6.18	7.57	8.74	9.76	10.7	11.6	12.4	13.1	13.8	14.5	15.1	15.8	16.4	16.9
	80	5.98	7.33	8.46	9.45	10.4	11.2	12.0	12.7	13.4	14.0	14.7	15.3	15.8	16.4
	90	5.80	7.11	8.21	9.16	10.0	10.9	11.6	12.3	13.0	13.6	14.2	14.8	15.3	15.9
	100	5.62	6.88	7.95	8.88	9.72	10.5	11.2	11.9	12.6	13.2	13.8	14.3	14.9	15.4
	110	5.48	6.71	7.75	8.66	9.48	10.3	11.0	11.6	12.3	12.9	13.4	14.0	14.5	15.0
	120	5.34	6.54	7.56	8.44	9.24	10.0	10.7	11.3	11.9	12.5	13.1	13.6	14.1	14.6
	130	5.20	6.37	7.36	8.22	9.00	9.72	10.4	11.0	11.6	12.2	12.7	13.3	13.8	14.3
	140	5.08	6.22	7.19	8.03	8.79	9.50	10.2	10.8	11.4	11.9	12.5	13.0	13.4	13.9
	150	4.98	6.10	7.05	7.87	8.62	9.31	10.0	10.6	11.1	11.7	12.2	12.7	13.2	13.7
	160	4.86	5.95	6.88	7.68	8.41	9.09	9.72	10.3	10.9	11.4	11.9	12.4	12.9	13.3
14"	40	9.78	12.0	13.8	15.5	16.9	18.3	19.6	20.7	21.9	22.9	24.0	24.9		
	50	9.44	11.6	13.3	14.9	16.4	17.7	18.9	20.0	21.1	22.1	23.1	24.1	25.0	
	60	9.10	11.1	12.9	14.4	15.8	17.0	18.2	19.3	20.3	21.3	22.3	23.2	24.1	24.9
	70	8.84	10.8	12.5	14.0	15.3	16.5	17.7	18.8	19.8	20.7	21.7	22.5	23.4	24.2
	80	8.56	10.5	12.1	13.5	14.8	16.0	17.1	18.2	19.1	20.1	21.0	21.8	22.6	23.4
	90	8.32	10.2	11.8	13.2	14.4	15.6	16.6	17.7	18.6	19.5	20.4	21.2	22.0	22.8
	100	8.12	9.94	11.5	12.8	14.0	15.2	16.2	17.2	18.2	19.0	19.9	20.7	21.5	22.2
	110	7.90	9.67	11.2	12.5	13.7	14.8	15.8	16.8	17.7	18.5	19.4	20.1	20.9	21.6
	120	7.72	9.45	10.9	12.2	13.4	14.4	15.4	16.4	17.3	18.1	18.9	19.7	20.4	21.1
	130	7.54	9.23	10.7	11.9	13.1	14.1	15.1	16.0	16.9	17.7	18.5	19.2	20.0	20.6
	140	7.36	9.01	10.4	11.6	12.7	13.8	14.7	15.6	16.5	17.3	18.0	18.8	19.5	20.2
	150	7.22	8.84	10.2	11.4	12.5	13.5	14.4	15.3	16.1	16.9	17.7	18.4	19.1	19.8
	160	7.08	8.67	10.0	11.2	12.3	13.2	14.2	15.0	15.8	16.6	17.3	18.1	18.7	19.4
16"	40	13.2	16.2	18.7	20.9	22.9	24.7	26.4	28.0	29.5	31.0	32.4			
	50	12.9	15.7	18.1	20.2	22.1	23.9	25.6	27.1	28.6	30.0	31.3	32.6		
	60	12.4	15.2	17.6	19.6	21.5	23.2	24.8	26.3	27.7	29.1	30.4	31.6	32.8	
	70	12.1	14.7	17.0	19.0	20.8	22.5	24.1	25.5	26.9	28.2	29.5	30.7	31.9	33.0
	80	11.7	14.4	16.6	18.5	20.3	21.9	23.4	24.9	26.2	27.5	28.7	29.9	31.0	32.1
	90	11.5	14.0	16.2	18.1	19.8	21.4	22.9	24.3	25.6	26.9	28.1	29.2	30.3	31.4
	100	11.2	13.7	15.8	17.6	19.3	20.9	22.3	23.7	24.9	26.2	27.3	28.5	29.5	30.6
	110	10.9	13.4	15.4	17.2	18.9	20.4	21.8	23.1	24.4	25.6	26.7	27.8	28.8	29.9
	120	10.7	13.1	15.1	16.8	18.4	19.9	21.3	22.6	23.8	25.0	26.1	27.2	28.2	29.2
	130	10.4	12.8	14.8	16.5	18.1	19.5	20.9	22.1	23.3	24.5	25.6	26.6	27.6	28.6
	140	10.2	12.5	14.5	16.2	17.7	19.1	20.4	21.7	22.8	23.0	25.0	26.1	27.0	28.0
	150	10.0	12.3	14.2	15.9	17.4	18.8	20.1	21.3	22.4	23.5	24.6	25.6	26.6	27.5
	160	9.84	12.1	13.9	15.6	17.0	18.4	19.7	20.9	22.0	23.1	24.1	25.1	26.0	27.0

Weir Flow Controls; "h" less than 1.4D

Diameter = 12"				Diameter = 14"				Diameter = 16"			
h	Q	h	Q	h	Q	h	Q	h	Q	h	Q
0.20	0.16	0.80	1.56	0.23	0.24	0.94	2.31	0.27	0.33	1.06	3.10
0.40	0.46	1.00	2.20	0.47	0.68	1.17	3.26	0.53	0.94	1.33	4.49
0.60	0.88	1.10	2.50	0.70	1.30	1.28	3.70	0.80	1.80	1.46	5.10

Figure 16.40-2

HEAD DISCHARGE TABLES FOR WELDED STEEL PIPE HOOD INLETS
FULL PIPE FLOW CONDITIONS
(For Dams)

HEAD IN FEET		4	6	8	10	12	14	16	18	20	22	24	26	28	30
Barrel Dia.	Barrel Length	Q (Discharge in cfs)													
18"	40	17.1	21.0	24.2	27.1	29.7	32.1	34.3	36.3	38.3	40.2				
	50	16.6	20.4	23.5	26.3	28.8	31.1	33.3	35.3	37.2	39.0	40.8			
	60	16.2	19.8	22.9	25.6	28.0	30.2	32.3	34.3	36.1	37.9	39.6	41.2		
	70	15.8	19.3	22.3	24.9	27.3	29.5	31.5	33.4	35.2	36.9	38.6	40.2	41.7	
	80	15.4	18.8	21.7	24.3	26.6	28.8	30.7	32.6	34.4	36.0	37.6	39.2	40.7	
	90	15.0	18.4	21.2	23.8	26.0	28.1	30.0	31.9	33.6	35.2	36.8	38.3	39.8	41.1
	100	14.7	18.0	20.8	23.3	25.5	27.5	29.4	31.2	32.9	34.5	36.0	37.5	38.9	40.3
	110	14.4	17.6	20.3	22.7	24.9	26.9	28.7	30.5	32.1	33.7	35.2	36.6	38.0	39.3
	120	14.1	17.3	19.9	22.3	24.4	26.4	28.2	29.9	31.5	33.0	34.5	35.9	37.3	38.6
	130	13.8	16.9	19.5	21.8	23.9	25.8	27.6	29.3	30.9	32.4	33.8	35.2	36.6	37.8
	140	13.4	16.6	19.2	21.5	23.5	25.4	27.1	28.8	30.4	31.8	33.2	34.6	35.9	37.2
	150	13.3	16.3	18.8	21.0	23.0	24.9	26.6	28.2	29.7	31.2	32.6	33.9	35.2	36.4
	160	13.1	16.0	18.5	20.7	22.7	24.5	26.2	27.8	29.3	30.7	32.1	33.4	34.6	35.8

Weir Flow Controls; "h" less than 1.4D

Diameter = 18"

h	Q	h	Q
0.30	0.44	1.20	4.30
0.60	1.27	1.50	6.06
0.90	2.43	1.65	6.89

Figure 16.40-3

Note: To determine "Q" for lengths not shown in the tables.

$$Q_2 = \sqrt{\frac{Q_1^2 \ (2 + K_p L_1)}{2 + K_p L_2}}$$

Subscript 1 = Value of length from table
Subscript 2 = Assumed value of length

Example: Find "Q" for 106' length of pipe
Welded steel pipe, Diameter 18" Head = 14

$$Q_2 = \sqrt{\frac{27.5^2 \ [2 + (.0155) \ (100)]}{2 + (.0155) \ (106)}} \qquad Q_2 = \sqrt{\frac{756.25 \times 3.550}{3.643}} \qquad Q_2 = 27.15 \text{ cfs}$$

To determine "Q" for heads not shown in the tables.

$$Q_2 = \sqrt{\frac{H_2 \ Q_1^2}{H_1}}$$

Subscript 1 = Value of H from table.
Subscript 2 = Assumed value of H.

Example: Find "Q" for 14.5' Head.
Welded Steel Pipe, Diameter 18", Length = 80'

$$Q_2 = \sqrt{\frac{14.5 \ (28.8^2)}{14}} \qquad Q_2 = \sqrt{\frac{14.5 \times 829.44}{14}} \qquad Q_2 = 29.31 \text{ cfs}$$

Corrugated Metal Pipe n = 0.025

Diameter of Pipe (I.D.)	8"	10"	12"	15"	18"	21"	24"	30"
K_p = Friction Loss	0.199	0.148	0.1157	0.0859	0.0674	0.0549	0.0459	0.0341

Welded Steel Pipe n = 0.012

Diameter of Pipe (O.D.)	6"	8"	10"	12"	14"	16"	18"
K_p = Frictional Loss	0.0672	0.0458	0.0340	0.0267	0.0217	0.0198	0.0155

5. PIPE FLOW (CONT'D)

Closed Conduit Spillways (cont'd)

The Hood Inlet (cont'd)

1. Tables show discharges with "h" equal to or greater than 1.4 D.
2. "h" must be equal to or greater than 1.4 D to obtain steady full pipe flow.
3. For approximate discharges when "h" is less than 1.4 D, see weir flow tables at bottom of sheet.
4. These tables do not take into consideration the bend loss K_m due to Angle "A". In most cases this loss is negligible if Angle "A" is less than 20°.
5. Absolute pressure (cavitation) will not be critical in ranges covered by these tables.
6. A proper anti-vortex device is necessary to obtain flow given in tables.
7. These tables computed from data contained in Technical Release No. 3.
8. S_n = neutral slope.

Corrugated Metal Pipe Arches. Where there is not sufficient head room for a round pipe, or where a greater flow area is desired below the water surface, a pipe arch may be used. Circular pipe ranging from 15 to 60 inches in diameter is used in forming arches with a span-rise of 18 x 11 inches to 72 x 44 inches. Figure 16.42 gives details of corrugated metal pipe arches and the areas and hydraulic radius of equivalent round pipe. Figure 16.43 gives the velocities for discharges (Q) of from 5 to 200 cubic feet per second for the various sizes of arch metal culverts.

Figure 16.44 shows friction head losses in feet per 1000 lineal feet of arched corrugated metal pipe.

Figure 16.45 shows the entrance and velocity head losses. The entrance and velocity head loss must be added to the friction loss, for the length of pipe being used, to get the total head required for the desired discharge capacity.

Problem:

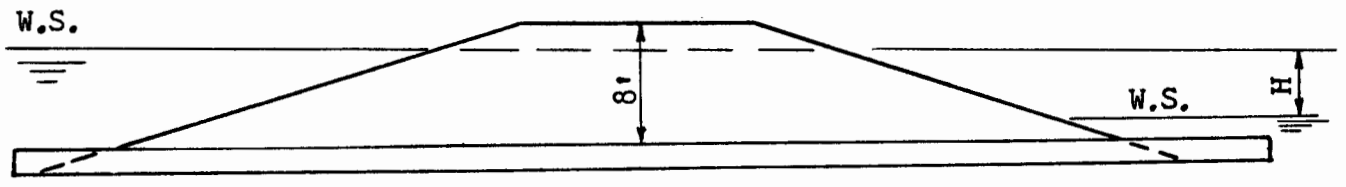

Figure 16.41

5. PIPE FLOW (CONT'D)

Closed Conduit Spillways (cont'd)

Corrugated Metal Pipe Arches (cont'd)

Problem: (cont'd)

Given: Discharge capacity required _____ 50 c.f.s.
Velocity at outlet not to exceed ____ 8 c.f.s.
Road fill over top of pipe _____ 8 feet
Length of pipe _____ 70 feet

Required: Size of corrugated metal pipe arch and total head required (H)

From Figure 16.44, select an arch with a span of 43 inches and a rise of 27 inches.

(H_f) friction loss per 1000 feet = 28.93 feet
v = 7.8 feet per second
H_f for 70 foot long pipe = $28.93 \times \frac{70}{1000} = 2.02$

Figure 16.45 gives the following entrance and velocity head loss: _____ 1.70

Total head (H) required: _____ 3.72

Diameter of Pipe of equal Periphery in Inches	Span in Inches	Rise in Inches	Pipe Arch		Circular Pipe	
			Area in Sq. Ft.	$*r_1$	Area in Sq. Ft.	$*r_2$
15	18	11	1.1	.28	1.23	.31
18	22	13	1.6	.34	1.77	.38
21	25	16	2.2	.40	2.40	.44
24	29	18	2.8	.45	3.14	.50
30	36	22	4.4	.56	4.91	.62
36	43	27	6.4	.68	7.07	.75
42	50	31	8.7	.79	9.62	.88
48	58	36	11.4	.91	12.57	1.00
54	65	40	14.3	1.02	15.90	1.13
60	72	44	17.6	1.12	19.64	1.25

$*r_1$ and $*r_2$ = hydraulic radius = $\frac{\text{Area}}{\text{Wetted Perimeter}}$

Figure 16.42

FULL FLOW VELOCITIES IN FT/SEC FOR ARCHED CORRUGATED METAL PIPE

Q cfs	Span Rise 18" 11" A = 1.1 Velocity	Span Rise 22" 13" A = 1.6 Velocity	Span Rise 25" 16" A = 2.2 Velocity	Span Rise 29" 18" A = 2.8 Velocity	Span Rise 36" 22" A = 4.4 Velocity	Span Rise 43" 27" A = 6.4 Velocity	Span Rise 50" 31" A = 8.7 Velocity	Span Rise 58" 36" A = 11.4 Velocity	Span Rise 65" 40" A = 14.3 Velocity	Span Rise 72" 44" A = 17.6 Velocity
5	4.5	3.1	2.3	1.8	1.1	.8	.6	.4	.4	.3
6	5.5	3.8	2.7	2.1	1.4	.9	.7	.5	.4	.3
7	6.4	4.4	3.2	2.5	1.6	1.1	.8	.6	.5	.4
8	7.3	5.0	3.6	2.9	1.8	1.3	.9	.7	.6	.5
9	8.2	5.6	4.1	3.2	2.0	1.4	1.0	.8	.6	.5
10	9.1	6.3	4.5	3.6	2.3	1.6	1.2	.9	.7	.6
12	10.9	7.5	5.5	4.3	2.7	1.9	1.4	1.1	.8	.7
14	12.7	8.8	6.4	5.0	3.2	2.2	1.6	1.2	1.0	.8
16	14.5	10.0	7.3	5.7	3.6	2.5	1.8	1.4	1.1	.9
18	16.4	11.3	8.2	6.4	4.1	2.8	2.1	1.6	1.3	1.0
20		12.5	9.1	7.1	4.5	3.1	2.3	1.8	1.4	1.1
25		15.6	11.4	8.9	5.7	3.9	2.9	2.2	1.8	1.4
30				10.7	6.8	4.7	3.5	2.6	2.1	1.7
35				12.5	8.0	5.5	4.0	3.1	2.4	2.0
40					9.1	6.3	4.6	3.5	2.8	2.3
45					10.2	7.0	5.2	4.0	3.1	2.6
50					11.4	7.8	5.8	4.4	3.5	2.8
60						9.4	6.9	5.3	4.2	3.4
70						10.9	8.1	6.1	4.9	4.0
80							9.2	7.0	5.6	4.5
90							10.3	7.9	6.3	5.1
100								8.8	7.0	5.7
110								9.7	7.7	6.3
120								10.5	8.4	6.8
130									9.1	7.4
140									9.8	8.0
150									10.5	8.5
160									11.2	9.1
170										9.7
180										10.2
190										10.8
200										11.4

Note: Span & Rise dimensions are in inches
V = velocity feet per second
Q = discharge cubic feet per second
A = end area of pipe in square feet

Figure 16.43

FRICTION LOSS IN FEET (H_f) PER 1000 LINEAL FEET OF ARCHED CORRUGATED METAL PIPE

$$H_f = \frac{L n^2 \ v^2}{2.208 \ r^{4/3}} \qquad n = 0.025$$

Q cfs	H_f/1000' Span 18" Rise 11"		H_f/1000' Span 22" Rise 13"		H_f/1000' Span 25" Rise 16"		H_f/1000' Span 29" Rise 18"		H_f/1000' Span 36" Rise 22"		H_f/1000' Span 43" Rise 27"		H_f/1000' Span 50" Rise 31"		H_f/1000' Span 58" Rise 36"		H_f/1000' Span 65" Rise 40"		H_f/1000' Span 72" Rise 44"	
	v	H_f	v	H_f	v	H_f	v	H_f	v	H_f	v	H_f	v	H_f	v	H_f	v	H_f	v	H_f
5	4.5	31.9	3.1	11.6	2.3	4.9	1.8	2.7	1.1	0.79	0.8	0.29	0.6	0.12	0.4	0.06	0.4	0.03	0.3	0.02
6	5.5	45.7	3.8	16.7	2.7	7.1	2.1	3.8	1.4	1.13	0.9	0.42	0.7	0.18	0.5	0.09	0.4	0.05	0.3	0.03
7	6.4	62.2	4.4	22.8	3.2	9.7	2.5	5.2	1.6	1.55	1.1	0.56	0.8	0.25	0.6	0.12	0.5	0.07	0.4	0.04
8	7.3	81.3	5.0	29.7	3.6	12.7	2.9	6.8	1.8	2.02	1.3	0.74	0.9	0.32	0.7	0.16	0.6	0.09	0.5	0.05
9	8.2	103.0	5.6	37.6	4.1	16.0	3.2	8.6	2.0	2.54	1.4	0.94	1.0	0.41	0.8	0.20	0.6	0.11	0.5	0.06
10	9.1	127.2	6.3	46.4	4.5	19.8	3.6	10.6	2.3	3.15	1.6	1.15	1.2	0.51	0.9	0.25	0.7	0.14	0.6	0.08
12	10.9	183.2	7.5	66.8	5.5	28.4	4.3	15.3	2.7	4.56	1.9	1.66	1.4	0.73	1.1	0.36	0.8	0.20	0.7	0.09
14	12.7	249.4	8.8	90.9	6.4	38.7	5.0	20.8	3.2	6.18	2.2	2.28	1.6	1.00	1.2	0.49	1.0	0.27	0.8	0.16
16	14.5	325.4	10.0	118.8	7.3	50.5	5.7	27.1	3.6	8.10	2.5	2.96	1.8	1.30	1.4	0.63	1.1	0.35	0.9	0.20
18	16.4	411.9	11.3	150.4	8.2	63.9	6.4	34.3	4.1	10.23	2.8	3.75	2.1	1.66	1.6	0.81	1.3	0.44	1.0	0.25
20			12.5	185.6	9.1	79.0	7.1	42.3	4.5	12.60	3.1	4.61	2.3	2.05	1.8	0.99	1.4	0.55	1.1	0.32
25			15.6	290.2	11.4	123.3	8.9	61.2	5.7	19.73	3.9	7.25	2.9	3.19	2.2	1.55	1.8	0.85	1.4	0.49
30							10.7	95.2	6.8	28.44	4.7	10.43	3.5	4.60	2.6	2.24	2.1	1.23	1.7	0.70
35							12.5	129.7	8.0	38.65	5.5	14.19	4.0	6.25	3.1	3.05	2.4	1.66	2.0	0.97
40									9.1	50.53	6.3	18.52	4.6	8.15	3.5	4.00	2.8	2.18	2.3	1.25
45									10.2	63.99	7.0	23.43	5.2	10.34	4.0	5.05	3.1	2.76	2.6	1.59
50									11.4	78.91	7.8	28.93	5.8	12.79	4.4	6.21	3.5	3.41	2.8	1.96
60											9.4	41.63	6.9	18.36	5.3	8.96	4.2	4.91	3.4	2.83
70											10.9	56.75	8.1	25.00	6.1	12.21	4.9	6.66	4.0	3.84
80													9.2	32.67	7.0	15.96	5.6	8.71	4.5	5.01
90													10.3	41.52	7.9	20.16	6.3	11.02	5.1	6.36
100															8.8	24.90	7.0	13.61	5.7	7.85
110															9.7	30.09	7.7	16.48	6.3	9.51
120															10.5	35.90	8.4	19.61	6.8	11.32
130																	9.1	23.02	7.4	13.26
140																	9.8	26.70	8.0	15.38
150																	10.5	30.66	8.5	17.67
160																	11.2	34.89	9.1	20.11
170																			9.7	20.71
180																			10.2	25.42
190																			10.8	28.34
200																			11.4	29.88

Note: Span & Rise dimensions are in inches
v = velocity feet per second
H_f = friction loss in feet
L = length in feet
n = roughness coefficient

Figure 16.44

ENTRANCE AND VELOCITY HEAD LOSS FOR FULL PIPE FLOW IN ARCHED CORRUGATED METAL PIPE

Q cfs	Span Rise 18" 11" A = 1.1 H	Span Rise 22" 13" A = 1.6 H	Span Rise 25" 16" A = 2.2 H	Span Rise 29" 18" A = 2.8 H	Span Rise 36" 22" A = 4.4 H	Span Rise 43" 27" A = 6.4 H	Span Rise 50" 31" A = 8.7 H	Span Rise 58" 36" A = 11.4 H	Span Rise 65" 40" A = 14.3 H	Span Rise 72" 44" A = 17.6 H
5	.6	.3	.2	.1	-	-	-	-	-	-
6	.9	.4	.2	.1	.1	-	-	-	-	-
7	1.3	.6	.3	.2	.1	-	-	-	-	-
8	1.6	.8	.4	.3	.1	-	-	-	-	-
9	2.1	1.0	.5	.3	.1	.1	-	-	-	-
10	2.6	1.2	.6	.4	.2	.1	-	-	-	-
12	3.7	1.7	.9	.6	.2	.1	.1	-	-	-
14	5.0	2.4	1.3	.8	.3	.2	.1	-	-	-
16		3.1	1.6	1.0	.4	.2	.1	.1	-	-
18		3.9	2.1	1.3	.5	.3	.1	.1	-	-
20		4.8	2.6	1.6	.6	.3	.2	.1	.1	-
25		7.6	4.0	2.5	1.0	.5	.3	.1	.1	.1
30			5.8	3.6	1.4	.7	.4	.2	.1	.1
35				4.9	2.0	.9	.5	.3	.2	.1
40				6.3	2.6	1.2	.7	.4	.2	.2
45					3.2	1.5	.8	.5	.3	.2
50					4.0	1.7	1.0	.6	.4	.3
60					5.8	2.7	1.5	.9	.5	.4
70						3.7	2.0	1.2	.7	.5
80						4.9	2.6	1.5	1.0	.6
90						6.1	3.3	1.9	1.2	.8
100							4.1	2.4	1.5	1.0
110							5.0	2.9	1.8	1.2
120								3.4	2.2	1.4
130								4.0	2.6	1.7
140								4.7	3.0	2.0
150								5.4	3.4	2.3
160									3.9	2.6
170									4.4	2.9
180									4.9	3.2
190									5.4	3.6
200										4.0

Note: Span & Rise dimensions are in inches
Q = discharge cubic feet per second
A = end area of pipe in square feet
Add the H_f for the actual pipe length to these values to determine the head required for full pipe flow.

Figure 16.45

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CONTENTS

PART 17

CONTOUR FARMING AND CONTOUR STRIP CROPPING

Subject	Page
1. General	17-1
2. Design	17-1
3. Layout	17-2
4. Construction	17-3
5. Maintenance	17-3
6. Equipment	17-4
7. Contour Farming	17-4

LIST OF FIGURES

PART 17

CONTOUR FARMING AND CONTOUR STRIP CROPPING

Figure Number	Title	Page
17.1	Usual Conditions found in Contoured Fields- - - - -	17-4
17.2	Using turnrow in listing- - - - - - - - - - - - - -	17-5
17.3	Listing out turnrow- - - - - - - - - - - - - - - -	17-5
17.4	Irregular areas and turnrow seeded to Legumes and grass -	17-5
17.5	Planting Row Crops on Terraced Land - Method #1 - -	17-6
17.6	Planting Row Crops on Terraced Land - Method #2 - -	17-7
17.7	Planting Row Crops on Terraced Land - Method #3 - -	17-8

PART 17

CONTOUR FARMING AND CONTOUR STRIP CROPPING

1. GENERAL

One of the basic engineering practices in conservation farming is the change of tillage and crop management operations from up and downhill to contour. In the same manner contour furrows or pits on rangeland reduce runoff and provide additional moisture for grasses.

Contour farming or contour strip cropping helps provide the multiple control needed to reduce runoff and siltation, which increase costs of lower-lying structures or damage other conservation measures. In the drier areas where water erosion is not a serious problem, these measures are the means whereby additional moisture is provided. In areas where the annual rainfall is 18 inches or less, moisture saved by contouring activities increases forage yields enough to more than offset the cost of applying these measures.

Drills or cultivators used on the contour provide ridges of earth that detain runoff or snowmelt so that it will enter the ground and be available to the growing plants. Since the size of the ridges will vary during the crop-growing season there will be differences in their effectiveness. That is the reason that long slopes need more than contour farming alone for season-long protection. Greater erosion control or moisture conservation is provided by a contour strip cropping system or a series of terraces supported by contour farming. Contouring alone usually has some furrows that are not entirely on the level so that runoff may be concentrated at one point and create a situation where break-overs will occur and create gullying hazards. Contour strip cropping partially overcomes the gullying hazards by redistributing the water through the alternate close growing and cultivated crop strips.

Conservation crop rotations and residue management are needed on all contour farmed or contour strip cropped fields. These agronomic measures increase the soil intake rates and reduce the volume of water that must be stored in the ridges. All waterways should be shaped and seeded to suitable grasses before or at the time contouring is performed on the fields. Prior seeding of waterways provides a safe outlet for water concentrated in the swales. Farming on the contour is sometimes needed to check runoff from the slopes so that the waterway can be seeded and a stand of grass established.

2. DESIGN

Most of the natural waterways, or swales, should be grassed when contour farming and strip cropping are expected to provide soil erosion control.

A diversion ditch may be needed to carry foreign runoff to a suitable discharge point and protect the slope that is contour farmed.

2. DESIGN (CONT'D)

Consideration should be given to the route taken by farm machinery to get in and out of the field to be farmed. Extra width to the waterways, odd areas seeded to grass and field border seedings provide a road that will not create erosion.

Field boundaries and fence lines should be changed to match the contouring. Odd areas created by contour farming square fields increase the difficulties and expenses of the farm operator.

3. LAYOUT

Contour guidelines across the slope may be level or on a terrace grade. Generally, the layout of lines start at the top of the slope. In some cases, the irregular topography may necessitate the layout of a key line farther down the slope as the first step. The other guidelines will then be adjusted to the key guideline. A much more farmable pattern of contour farming may be the result of following this procedure.

The guidelines may have sharp curves so these should be smoothed out and rechecked for allowable grade. Each of the guidelines should be measured with a tape so it parallels the key guideline or spaced at terrace intervals on the slope as required in some states. If guidelines are laid out parallel to each other, any line at a uniform width from the key line should be checked for grade. If satisfactory the second line can be utilized and additional lines laid out as long as the grade remains satisfactory. Whenever the grades on parralleled lines become excessive, additional key guidelines may be required and the above procedures followed. The technician should plan a system to reduce the number of short row or odd areas but a few widely spaced guidelines on a slope may be more detrimental than beneficial.

The widths of the contour strips do not have to be limited to the same spacing as the guidelines. The alternate strips of close growing and cultivated crops may vary within the field and include one or two guidelines. The method of farming out the lands between guidelines should determine the boundary of a strip. Contour strips should not be less than 3 rods nor more than 25 rods wide.

The layout of a field for contouring or strips includes more than laying out the guidelines. If these practices are new to the operator the technician should stake additional lines above and below the guidelines to show how the field should be farmed and where the odd areas will occur. It can then be explained how the machinery can be turned around and the odd areas farmed. The odd areas can also be seeded to grass or forage crops for hay, pasture, or seed.

Lines can be staked by using lath, wires with cloth or plastic flags, or throwing up small mounds of earth with a shovel. Plowing out of the lines should be done before the technician leaves the field. In this way, stakes can be reclaimed and the farmer will not be confused by the several lines staked out across the slope.

3. LAYOUT (CONT'D)

Stakes or flags at the ends of contour guidelines on field boundaries or fence lines will serve as reference points for all future farming activities and eliminate a re-survey.

On some classes of land where the topography is rough, irregular, and the length of slopes is less than 200 to 250 feet, contour farming may be the only mechanical practice that can be applied. In these cases, a greater modification of the guidelines is permissible. The maximum deviation from a level line is 2 feet per hundred for a maximum length of 300 feet.

4. CONSTRUCTION

Plowing, listing, or drilling on the contour is always started at the guideline when first performed. When the lands are established future operations can start at the edges.

There are several methods of contour farming the area between guidelines. Generally the machinery operator starts on a guideline and, by parrelling this line, farms up halfway and down halfway between any pair of guidelines. When the fields are quite irregular and there is wide variance between the guidelines, the farming of lands may need to be changed to one-third up and two-thirds down or some other proportion. The principle point to remember is to keep as many rows as much on the contour as possible, and the field technician should be able to suggest the arrangement of lands for each guideline.

Long rows can be farmed first with a narrow strip left throughout the entire length of the field so the odd areas can be farmed. Then the strip left for turning should be farmed. In some cases, the odd areas may be seeded to grasses for permanent turnrows. In some locations, the odd areas and short rows are seeded to grasses so that the farming areas are always uniform in width and which accomodates the farm machinery that is used.

The Figures 17.1 to 17.7 show how adjustments can be made when planting a field using the guidelines. The same procedures are followed when contour farming a field on which a system of terraces have been constructed.

The cultivation and harvesting of row crops will depend on how the field was planted but will generally be the reverse, so to speak, of the planting procedure. The turnland through the length of the field will be cultivated or harvested first, then the short rows, and finally the long rows parallel to the guidelines.

The square boundaries of the fields should be changed to match the contour farming and lessen the acreage of odd areas. Any remaining odd areas may then be farmed, grassed, or prepared for a wildlife area.

5. MAINTENANCE

Contour guidelines must be maintained. Backfurrowing of the guideline

5. MAINTENANCE (CONT'D)

at the end of the growing season is one method. Grassed turnrows and odd areas will give permanent boundaries so the fields can be farmed the same each year. Permanent boundaries on a strip cropping system will give the same results.

6. EQUIPMENT

Normal farm equipment is all that is needed to do contour farming or contour strip cropping.

7. CONTOUR FARMING

Planting Crops in Contoured Fields

Crop rows that parallel contour guide lines, reduce run-off and erosion.

The following Figure 17.1 gives the principles of

1. farming the long row areas above and below guide lines
2. farming the remaining irregular point row areas between the long areas
3. locating the turnrows between contour guide lines.

The turnrow areas can be farmed the same as the rest of the field (Figures 17.2 and 17.3) or seeded to annual or permanent vegetation (Fig. 17.4). Permanent vegetation in the irregular areas and turnrows makes the planting, cultivating and harvesting much easier.

USUAL CONDITIONS FOUND IN CONTOURED FIELDS

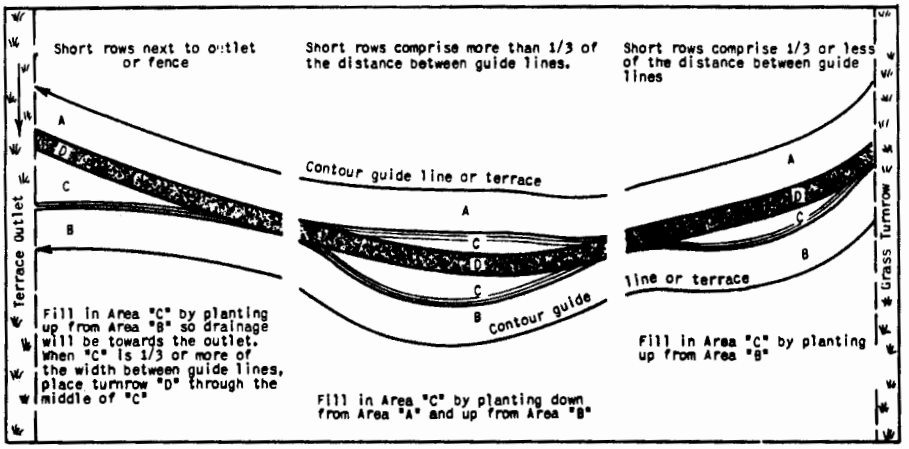

Short rows next to outlet or fence
Short rows comprise more than 1/3 of the distance between guide lines.
Short rows comprise 1/3 or less of the distance between guide lines
Terrace outlet
Grass turnrow
Contour guide line or terrace
A
B
C
D
Fill in Area "C" by planting up from Area "B" so drainage will be towards the outlet. When "C" is 1/3 or more of the width between guide lines, place turnrow "D" through the middle of "C"
Fill in Area "C" by planting down from Area "A" and up from Area "B"
Fill in Area "C" by planting up from Area "B"
line or terrace
Contour guide

Figure 17.1

A. Plant long rows down from upper guide line nearly halfway at narrowest place between guide lines.
B. Next plant long rows up from lower guide line to width of turnrow D at narrowest place.
C. Fill in short rows using D as an unplanted turnrow of 4 to 8 rows.
D. Plant long rows in turnrow (D) after short rows, or seed to annual or perennial vegetation.

7. CONTOUR FARMING (CONT'D)

Using turnrow in listing
Figure 17.2

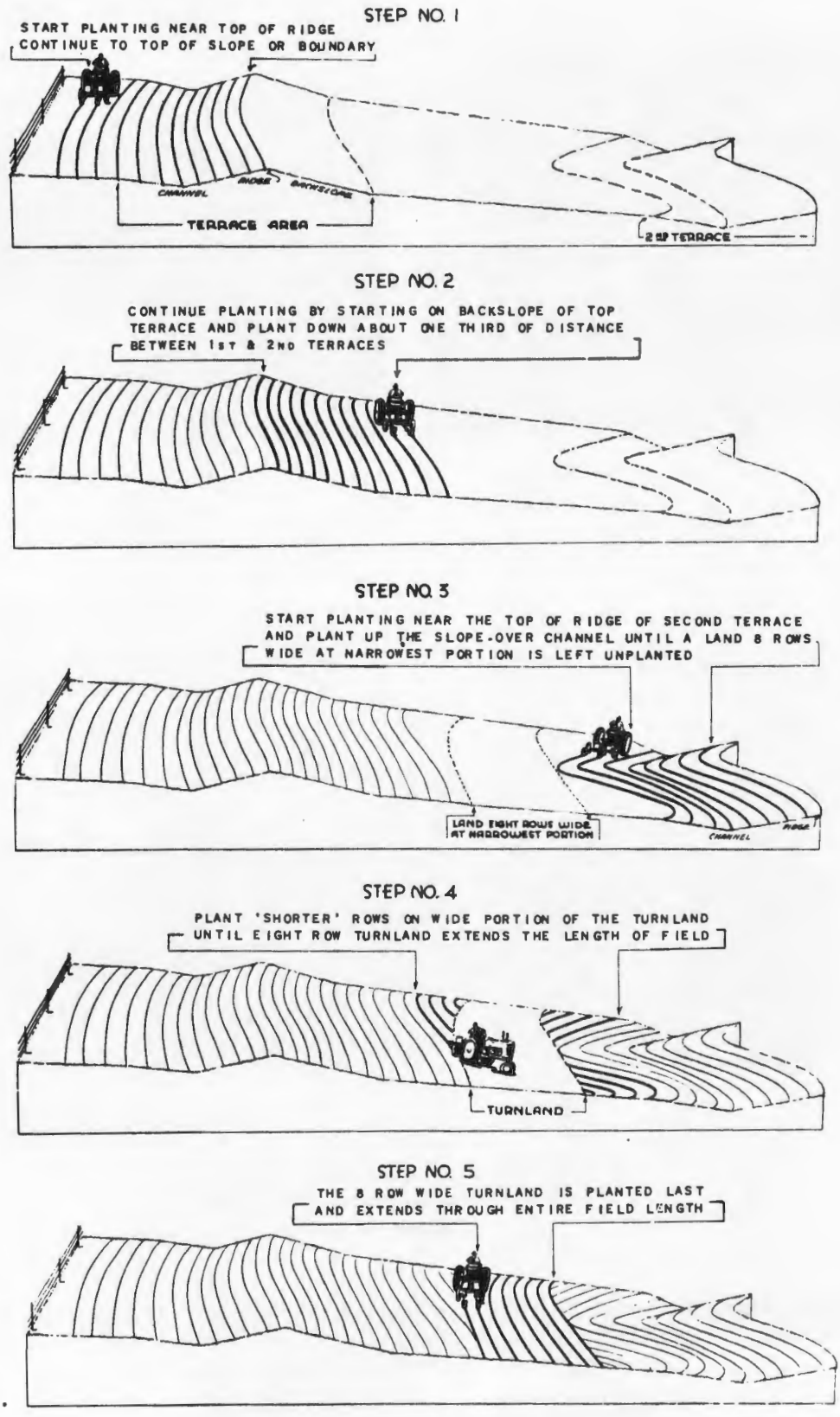
Listing out turnrow
Figure 17.3

Irregular areas and turnrow
seeded to legumes and grass
Figure 17.4

Where terraces are not used, annual backfurrowing or deadfurrowing is necessary to retain the exact location of the guide lines. The guide lines should be further identified by markers in adjacent fences, or strips of permanent vegetation.

PLANTING ROW CROPS ON TERRACED LAND

METHOD No. 1


STEP NO. 1
START PLANTING NEAR TOP OF RIDGE
CONTINUE TO TOP OF SLOPE OR BOUNDARY
CHANNEL
RIDGE
BACKSLOPE
TERRACE AREA
2 UP TERRACE
STEP NO. 2
CONTINUE PLANTING BY STARTING ON BACKSLOPE OF TOP TERRACE AND PLANT DOWN ABOUT ONE THIRD OF DISTANCE BETWEEN 1ST & 2ND TERRACES
STEP NO. 3
START PLANTING NEAR THE TOP OF RIDGE OF SECOND TERRACE AND PLANT UP THE SLOPE-OVER CHANNEL UNTIL A LAND 8 ROWS WIDE AT NARROWEST PORTION IS LEFT UNPLANTED
LAND EIGHT ROWS WIDE AT NARROWEST PORTION
CHANNEL
RIDGE
STEP NO. 4
PLANT 'SHORTER' ROWS ON WIDE PORTION OF THE TURNLAND UNTIL EIGHT ROW TURNLAND EXTENDS THE LENGTH OF FIELD
TURNLAND
STEP NO. 5
THE 8 ROW WIDE TURNLAND IS PLANTED LAST AND EXTENDS THROUGH ENTIRE FIELD LENGTH

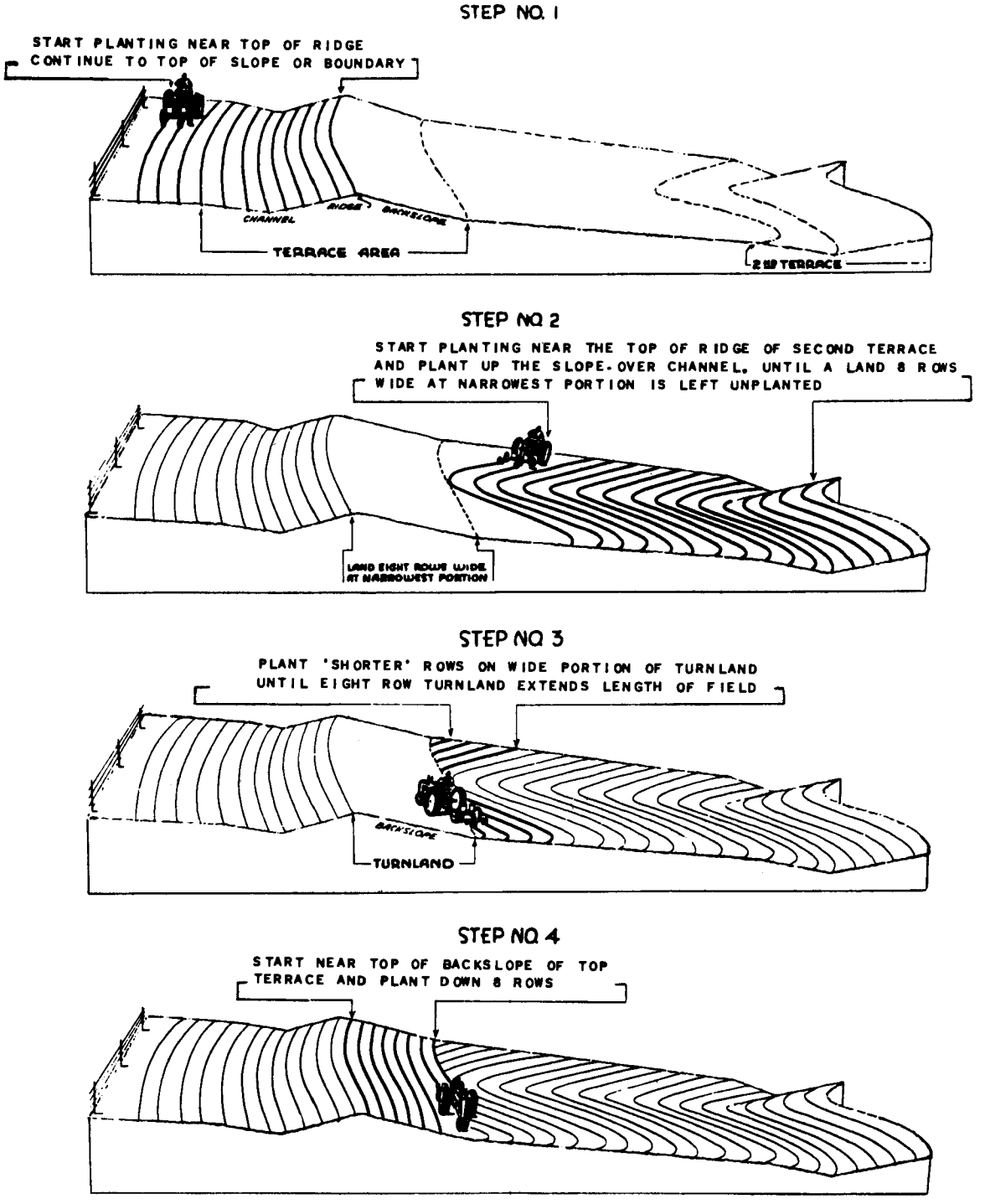
From USDA, SCS
Milwaukee, Wisc.

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

Figure 17.5

PLANTING ROW CROPS ON TERRACED LAND

METHOD No. 2


STEP NO. 1
START PLANTING NEAR TOP OF RIDGE
CONTINUE TO TOP OF SLOPE OR BOUNDARY
CHANNEL
RIDGE
BACKSLOPE
TERRACE AREA
2ND TERRACE
STEP NO 2
START PLANTING NEAR THE TOP OF RIDGE OF SECOND TERRACE
AND PLANT UP THE SLOPE-OVER CHANNEL, UNTIL A LAND 8 ROWS
WIDE AT NARROWEST PORTION IS LEFT UNPLANTED
LAND EIGHT ROWS WIDE
AT NARROWEST PORTION
STEP NO 3
PLANT 'SHORTER' ROWS ON WIDE PORTION OF TURNLAND
UNTIL EIGHT ROW TURNLAND EXTENDS LENGTH OF FIELD
BACKSLOPE
TURNLAND
STEP NO 4
START NEAR TOP OF BACKSLOPE OF TOP
TERRACE AND PLANT DOWN 8 ROWS

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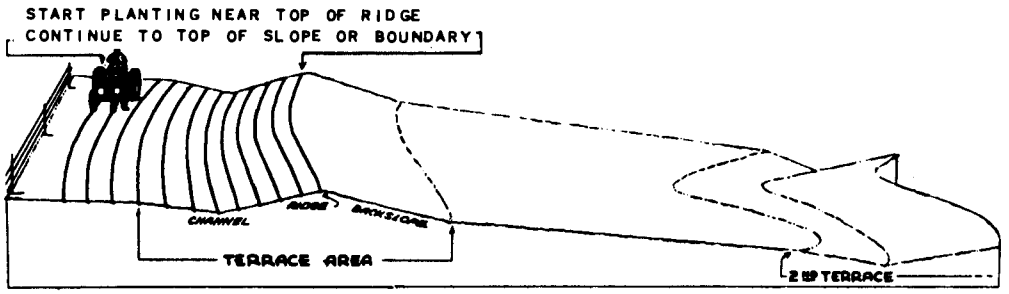
SOIL CONSERVATION SERVICE

Figure 17.6

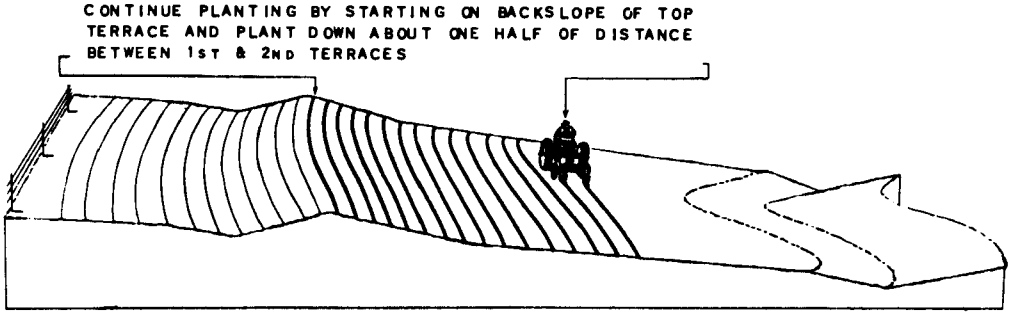
PLANTING ROW CROPS ON TERRACED LAND

METHOD No. 3

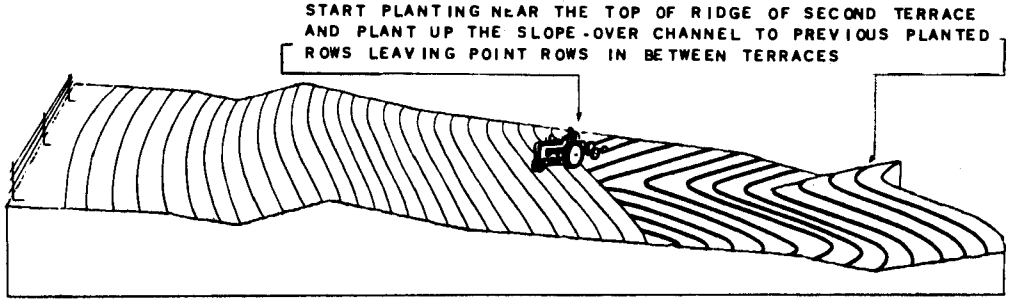
STEP NO. 1



STEP NO 2


CONTINUE PLANTING BY STARTING ON BACKSLOPE OF TOP TERRACE AND PLANT DOWN ABOUT ONE HALF OF DISTANCE BETWEEN 1ST & 2ND TERRACES

STEP NO 3


START PLANTING NEAR THE TOP OF RIDGE OF SECOND TERRACE AND PLANT UP THE SLOPE-OVER CHANNEL TO PREVIOUS PLANTED ROWS LEAVING POINT ROWS IN BETWEEN TERRACES

If you don't want to bother with point rows you can just leave the uneven area in grass or small grain.

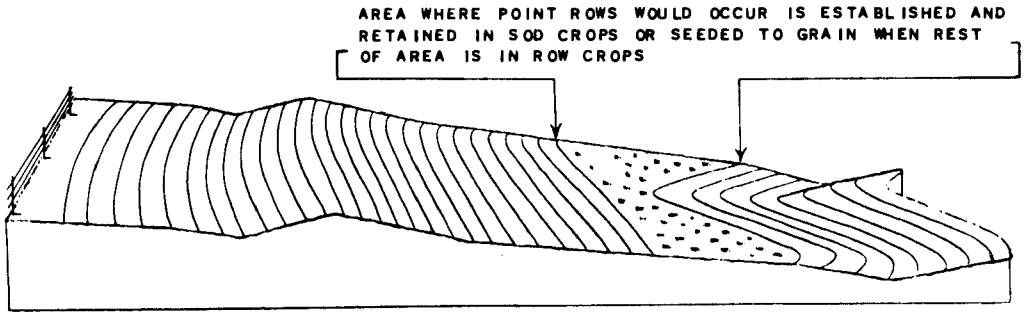

AREA WHERE POINT ROWS WOULD OCCUR IS ESTABLISHED AND RETAINED IN SOD CROPS OR SEEDED TO GRAIN WHEN REST OF AREA IS IN ROW CROPS

Figure 17.7

From USDA, SCS
Milwaukee, Wisc.

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CONTENTS

PART 18

CONTOUR FURROWS AND PITTING ON PASTURE AND RANGE LAND

Subject	Page
1. General	18-1
Purpose	18-1
Adaptability	18-4
2. Surveys for Furrows	18-6
3. Design for Furrows	18-6
4. Layout for Furrows	18-13
5. Construction for Furrows	18-13
Water Storage	18-13
6. Maintenance	18-14
7. Pitting	18-14

LIST OF FIGURES

PART 18

CONTOUR FURROWS AND PITTING ON PASTURE AND RANGE LAND

Figure Number	Title	Page
18.1	Total Annual Runoff from Pasture Plots	18-2
18.2	Maximum Annual Peak Rates of Runoff from Pasture Plots	18-2
18.3	Annual Runoff from Pasture Plots	18-3
18.4	Summary of Grazing and Utilization on Pastures Treated in 1939 at Archer Field Station	18-4
18.5	Soil Moisture Distribution on Furrowed and Unfurrowed areas	18-5
18.6	Rainfall Intensity Frequency Curves	18-8
18.7	Interpolated values of "C" for use in Rational Formula	18-9
18.8	Runoff producing characteristics of Watershed showing factors for each characteristic for various Watershed types	18-9
18.9	Spacing of Contour Furrows of Varying Channel Capacity for Different Depths of Runoff	18-10
18.10	Spacing of Contour Furrows, 2-year Frequency	18-11
18.11	Spacing of Contour Furrows, 5-year Frequency	18-12
18.12	Pasture Furrow Cross Section	18-15

PART 18

CONTOUR FURROWS AND PITTING ON PASTURE AND RANGE LAND

1. GENERAL

Purposes

The purpose of contour furrows or pitting on pasture and range land is to reduce runoff and erosion, improve plant cover, conserve moisture, and increase forage yields. Contour furrows reduce water erosion by storing the runoff and by acting as small desilting basins. In the interest of flood control, the establishment of contour furrows on pasture or range land may be one of the most effective mechanical treatments that can be applied. The exception to these multiple benefits might be the sandier and heavy claypan areas of the state.

Contour furrowing is one of several soil and water conservation practices that may be needed on tame or native pastures. This practice consists of the construction of small channels spaced at regular intervals across slopes, to provide water storage below the surface level of the ground. A furrow slice or ridge of sod is undesirable for it does not distribute excess water in a uniform manner. The excavated soil and sod is broken up and scattered over a large area to prevent the deep burial of grasses. Contour furrows are always laid out and constructed so they are level and have closed ends. Pitting machines are operated on the approximate contour.

Soil Conservation Service research at the Central Great Plains Experimental Watershed near Hastings, Nebraska has given us some important hydrological data on rainfall and runoff from native grass areas. The experiment which is still in progress was first initiated in 1939. During 1940 through 1945 the experiment measured effects of furrows on runoff for both heavily and lightly grazed pastures and on unfurrowed controls. The soil at the site of the studies is designated as a very deep soil with thick medium-textured top soil and thick, moderately slowly permeable subsoil and moderately permeable substrata on loess uplands.

Figure 18.1 shows the total annual runoff from the pasture areas, as well as the total annual rainfall at the Central Meteorological Station for the period of 1940 to 1945.

1. GENERAL (CONT'D)

TOTAL ANNUAL RUNOFF FROM PASTURE PLOTS *

Treatment	Ave. Slope %	Total Runoff ** (in inches) 1940	1941	1942	1943	1944	1945	6-yr Ave.
None (check) Heavily grazed	6.9	0.68	1.36	1.62	1.38	1.72	1.34	1.35
None (check) Lightly grazed	6.8	0.75	1.20	0.55	0.89	0.32	0.34	0.68
Furrowed *** Heavily grazed	6.8	0.03	0.10	0.20	0.09	0.27	0.20	0.15
Furrowed *** Lightly grazed	7.0	0.14	0.10	0.03	0.05	0.06	0.06	0.07
Annual rainfall at station	-	13.0	26.3	31.8	16.2	29.7	22.6	23.2

* No forage yield data were measured at this station.

** The runoff data from the contour furrowed plots are not adjusted to compensate for the relatively small unfurrowed area between the lowest furrow and the weir on each plot.

*** Data are from two plots, one of which had contour furrows horizontally spaced at 10' to 12' intervals, and the other 16' to 18'. The furrows were 4" deep and 6" wide.

Figure 18.1

Figure 18.1 shows that during the 6-year period:

(1) The total runoff was reduced 50% by reduced grazing.
(2) The total runoff was reduced 90% by contour furrows.
(3) The total runoff from the furrowed pastures, lightly grazed, was only 1/3 of 1% of the rainfall.

Figure 18.2 shows the effect of vegetative cover and mechanical treatment of pasture areas on the peak rate of runoff. These results are for the same pasture plots and period as in Figure 18.1.

MAXIMUM ANNUAL PEAK RATES OF RUNOFF FROM PASTURE PLOTS *

Treatment	Ave. Slope %	Peak Rates of Runoff ** (Inches per hr.) 1940	1941	1942	1943	1944	1945	6-year Ave.
None (check) Heavily grazed	6.9	0.51	1.11	0.68	1.43	0.95	1.38	1.01
None (check) Lightly grazed	6.8	0.60	1.01	0.27	1.55	0.29	0.61	0.72
Furrowed *** Heavily grazed	6.8	0.03	0.06	0.07	0.11	0.14	0.16	0.10
Furrowed *** Lightly grazed	7.0	0.03	0.04	0.03	0.11	0.05	0.13	0.07
Annual rainfall at station	-	13.0	26.3	31.8	16.2	29.7	22.6	23.2

Figure 18.2

1. GENERAL (CONT'D)

Maximum Annual Peak Rates of Runoff from Pasture Plots * (cont'd)

* No forage yield data were measured at this station.
** The runoff data from the contour furrowed plots are not adjusted to compensate for the runoff from the relatively small unfurrowed area between the lowest furrow and the weir on each plot.
*** Data are from two plots, one of which had contour furrows horizontally spaced at 10' to 12' intervals, and the other at 16' to 18'. The furrows were 4" deep and 6" wide.

In 1947 the runoff experiments were revised to determine the effects of pitting (eccentric discing) and narrower furrow spacings with the grazing to be the same on all plots. The results of these experiments are shown in Figure 18.3.

ANNUAL RUNOFF FROM PASTURE PLOTS *

Treatment	Ave. Slope %	Total Runoff ** (in inches) 1947	1948	1949	1950	4-yr. Ave.
None - Moderately grazed	6.9	1.28	0.14	1.90	1.43	1.19
Eccentric disced - Moderately grazed	6.8	0.52	0.05	0.86	0.91	0.59
Contour furrowed - Moderately grazed 12' - 18'	6.8	0.16	0.02	0.30	0.29	0.19
Contour furrowed - Moderately grazed 4' - 5'	6.9	0.04	0.006	0.02	0.21	0.07
Total rainfall (inches)		21.0	17.5	26.8	22.4	21.92

* No forage yield data were measured at this station.
** The runoff data from the contour furrowed plots are not adjusted to compensate for the relatively small unfurrowed area between the lowest furrow and the weir on each plot.

Figure 18.3

The changes in furrow spacing in the 1947 to 1950 experiments were decided upon after reviewing the 1941 sample results on soil moisture distribution on furrowed and unfurrowed areas. The information received from this experiment is shown in Figure 18.5. It will be noted that the percent of soil moisture is higher on the furrowed plots than on the unfurrowed plots, but that the moisture is not well distributed through the section. From these data it was decided that 12' to 18' spacing between furrows was too great.

Summarizing: The 10-year period of record obtained at the Central Great Plains Experimental Watershed shows that the reduction in both peak rates and total runoff from furrowed pastures is highly significant and that furrows should not be placed more than 12 feet apart for the good distribution of soil moisture. It is preferred that furrow spacings be 4 to 5 feet apart or less. It also shows that light grazing and treatment with an eccentric disc was significant in this case but not as effective in reducing runoff as light grazing and furrows.

1. GENERAL (CONT'D)

Annual Runoff from Pasture Plots * (cont'd)

The increased amount of water absorbed by the soil and its aeration as a result of contour furrows may stimulate plant growth and make it possible under conservative use to obtain both higher yields of forage and more plant residues. This is substantiated by the following research data obtained from the "1949 Annual Report on Approved Line Projects in Wyoming," by O. K. Barnes. These data cover work at the Archer Field Station located about 9 miles east of Cheyenne, Wyoming. The work is a cooperative undertaking of the Soil Conservation Service Research Division with the Wyoming Agricultural Experiment Station, the Bureau of Plant Industry and Soils and Agricultural Engineering. The higher yields of forage obtained on contour furrowed land are reflected in the number of sheep days of grazing, the lamb gain per acre and the lamb gain per head. The plant residues remaining at the end of the grazing season were clipped and weighed and the results shown in Figure 18.4.

SUMMARY OF GRAZING AND UTILIZATION ON PASTURES
TREATED IN 1939 AT ARCHER FIELD STATION.

(Averages for 1940 to 1949, inclusive)*

Treatment	Sheep Days Per Acre	Lamb Gain Per Acre	Lamb Gain Per Head	Pounds per acre Grass left at end of season **
Check (Untreated)	64	32.5	53.0	217
Pitted (Eccentric disc)	78	38.6	51.9	272
Grooved (Contour furrows) ***	78	40.7	55.5	330

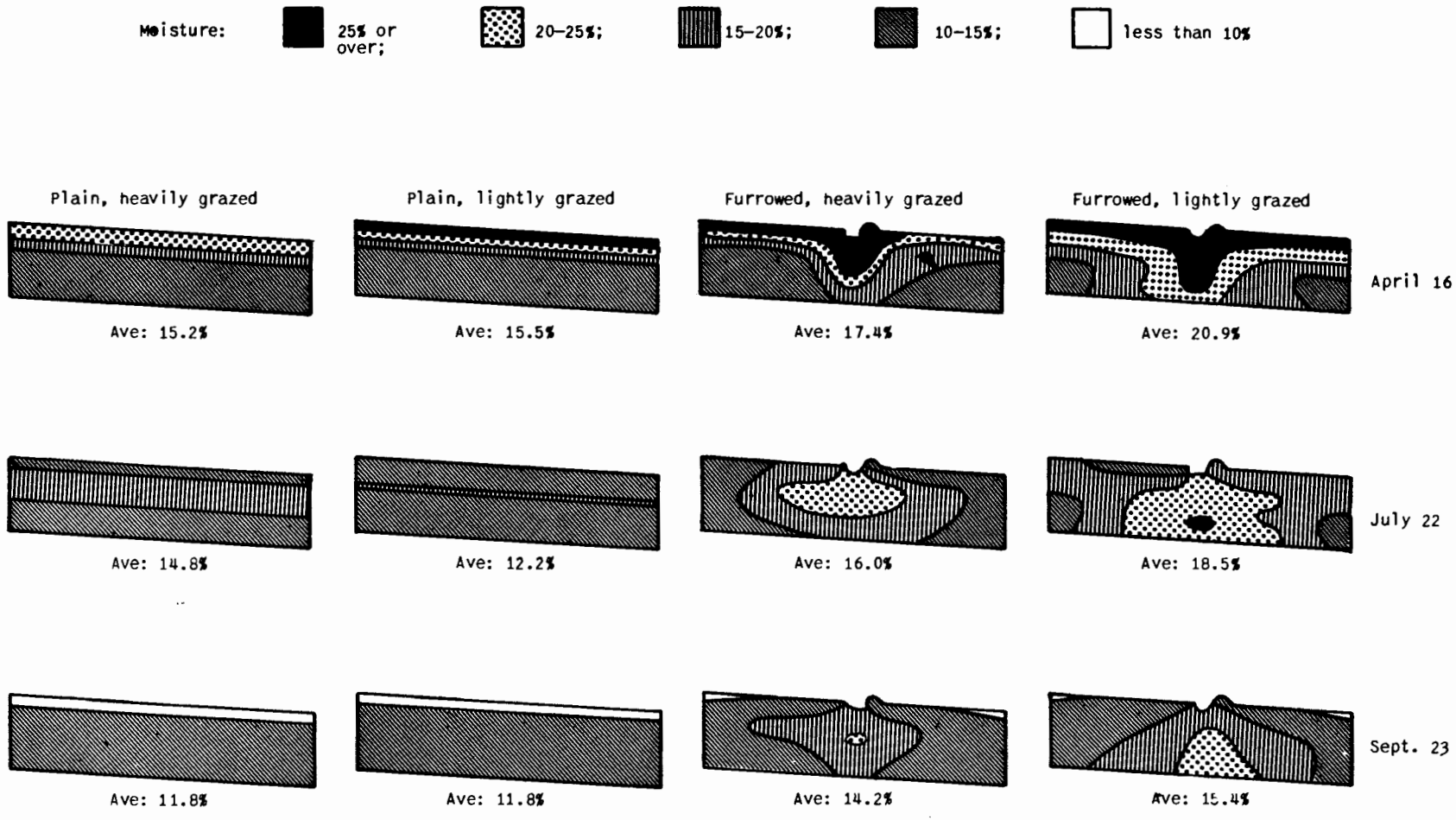
* No Runoff measurements were made at this station.
** Average for eight years. Data were not obtained for 1940 and 1947.
*** These contour furrows were 6 inches wide, 4 to 5 inches deep and spaced 2 feet apart.

Figure 18.4

Adaptability

Contour furrows or pits are adaptable to much of the native rangeland in this State. They are also suitable on permanent tame pastures where reduction of damages from runoff and siltation are the primary objectives. In general, they are adaptable to areas where there is:

1. A condition where the plant cover is below its potential.
2. Annual runoff.
3. Water erosion of the soil.
4. Soil that has sufficient depth and is free of rocks or large roots.



SOIL MOISTURE DISTRIBUTION ON FURROWED AND UNFURROWED AREAS
Measurements taken to a depth of 4 feet

Scale 1" equals 8'

Source
GREAT PLAINS HYDROLOGIC STATION
Hastings, Nebraska
1941

Figure 18.5

1. GENERAL (CONT'D)

Adaptability (cont'd)

Refer to the local technical standards for more specific reference as to areas suitable for and in need of contour furrows or pitting and for grazing management. Since farm equipment generally will be used for their construction, contour furrows or pits should not be planned for steep slopes or hummocky land which cannot be readily furrowed on the contour or pitted on the approximate contour. The beneficial effects of furrows and pits on forage yield will probably be the greatest on deep to moderately deep medium-textured permeable soils in moisture deficient areas. Treatment of this type is also beneficial in areas where there are high intensity showers during the growing season, rapid snowmelt, or where rhizomatous mid grasses can replace the short grasses on rangeland.

2. SURVEYS FOR FURROWS

After a determination has been made that the soil and slope are suitable, there are some points that should be given careful consideration before laying out the furrows. One of these that should be discussed with the operator is the location on the grassed area of routes of travel frequently used by the operator with vehicles. These will include routes of travel to water developments, salt grounds, corrals, fence lines and possibly others. These routes of travel should not be crossed with the furrows. Another item that should be given consideration is the effect of contour furrowing on water supply. Contour furrowing builds up underground waters and is beneficial to wells and springs, but it may be detrimental to stockwater ponds located on the same drainage. Stockwater ponds with small drainage areas above them may be materially affected, if a considerable portion of the drainage area above them is contour furrowed.

3. DESIGN FOR FURROWS

Contour furrows may vary in size from 3 to 6 inches or more in width to 3 to 6 inches in depth. They may vary in shape from that of a "V" to square or rectangular. The depth of the soil should be used as the main factor to determine the depth of the furrow to be constructed. Since furrows become most effective when vegetation is growing in them it is best not to make them so deep that infertile subsoil is exposed. Another factor to be considered is the kind of equipment the operator may have to construct the furrows. The shape and width of the furrow should be governed largely by the stability of the soil. For stable soils where the side walls of the furrow do not slough readily, a rectangular furrow 4 to 6 inches wide is recommended. For unstable soils the furrows should be at least 6 inches in width. Narrow furrows, 4 to 6 inches wide, spaced closely together, 2 to 5 feet apart, have a decided advantage over wider furrows spaced at greater distances apart. The narrow furrows, spaced closely together, give a better distribution of runoff water and higher yields of forage. Also, the furrow slices are more readily spread and the furrows are more easily crossed by motor vehicles and livestock, especially old ewes.

3. DESIGN FOR FURROWS (CONT'D)

The effectiveness of contour furrows to hold water will depend on the degree of slope, smoothness of the surface and the accuracy with which they are constructed. Their longevity will be determined by the stability of the soil and soil movement on the area immediately above them.

Furrow sizes and spacing can be designed in the same manner as the spillway for an earth dam by using rainfall data and estimating runoff conditions.

Figure 18.6 gives rainfall intensities in inches per hour for several states for 2- or 5-year frequencies. Field personnell will be expected to exercise judgment on the frequency period to be used. If the watershed area to be furrowed is above a critical area (farmstead, irrigation ditch, deep gullies, etc.) that needs considerable protection, then the 5-year frequency chart should be used. The 2-year frequency is ample where conditions are on the favorable side.

After determining the amount of rain to be expected in a one-hour period, it is then necessary to determine the characteristics of the watershed on which the furrows will be placed. Figure 18.8 has numerical factors for the various degrees of variance in slope, soil infiltration, vegetal cover and surface to be used in the calculation of runoff. Totaling the various characteristic factors gives the watershed coefficient to be used.

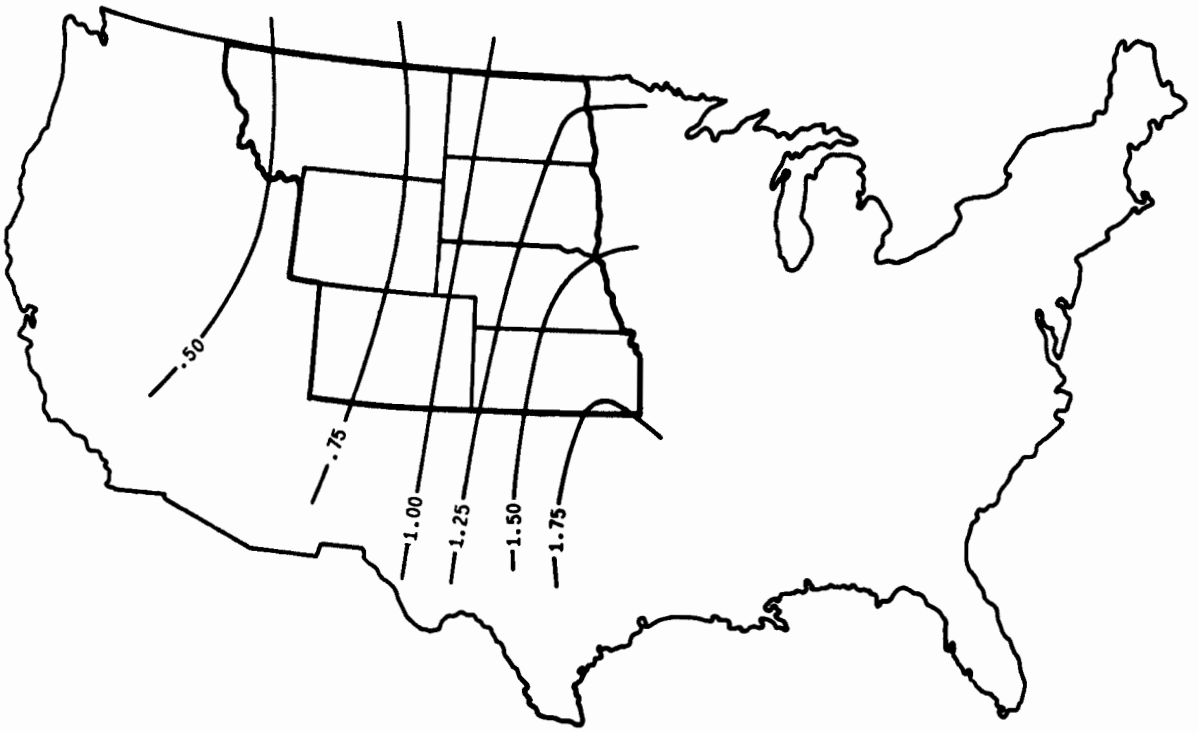
The runoff, in inches, is the product of the rainfall and the runoff coefficient "C". When the runoff is calculated, Figure 18.9 will then show the spacing to be used for various types of furrows.

Figures 18.10 and 18.11 give furrow spacings according to four typical geographical points, a watershed characteristic that is normal, a runoff coefficient of "C" equals 0.31 and 0.35 and for various furrow widths and depths. The same procedure can be followed for different conditions or localities.

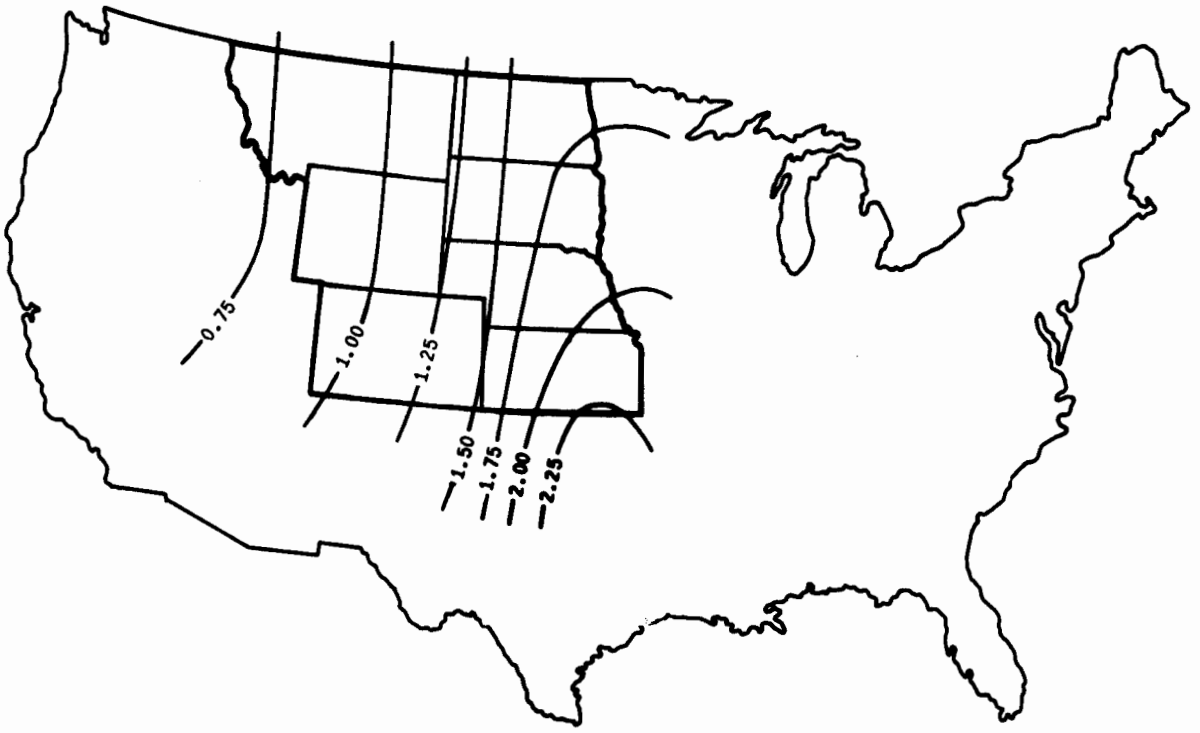
From the latest hydrologic data the value of runoff coefficient "C" is determined for various frequencies by the formula:

$$C = C \text{ maximum } \frac{(T)^x}{100}$$

where "C" maximum is for 100 years
T is frequency in years and
x = 0.19



One hour rainfall in inches, to be expected once in 2 years



One hour rainfall in inches, to be expected once in 5 years

RAINFALL INTENSITY FREQUENCY CURVES

Figure 18.6

3. DESIGN FOR FURROWS (CONT'D)

Using the preceding formula, we have the following "C" values to use:

INTERPOLATED VALUES OF "C" FOR USE IN RATIONAL FORMULA

Total of Watershed Physical Characteristics	Two year Frequency	Five-Year Frequency
10	.16	.18
12	.18	.21
14	.20	.23
16	.23	.26
18	.25	.29
20	.28	.32
22	.30	.34
24	.31	.35
26	.32	.37
28	.33	.38
30	.35	.40

Figure 18.7

RUN-OFF PRODUCING CHARACTERISTICS OF WATERSHEDS SHOWING FACTORS FOR EACH CHARACTERISTIC FOR VARIOUS WATERSHED TYPES

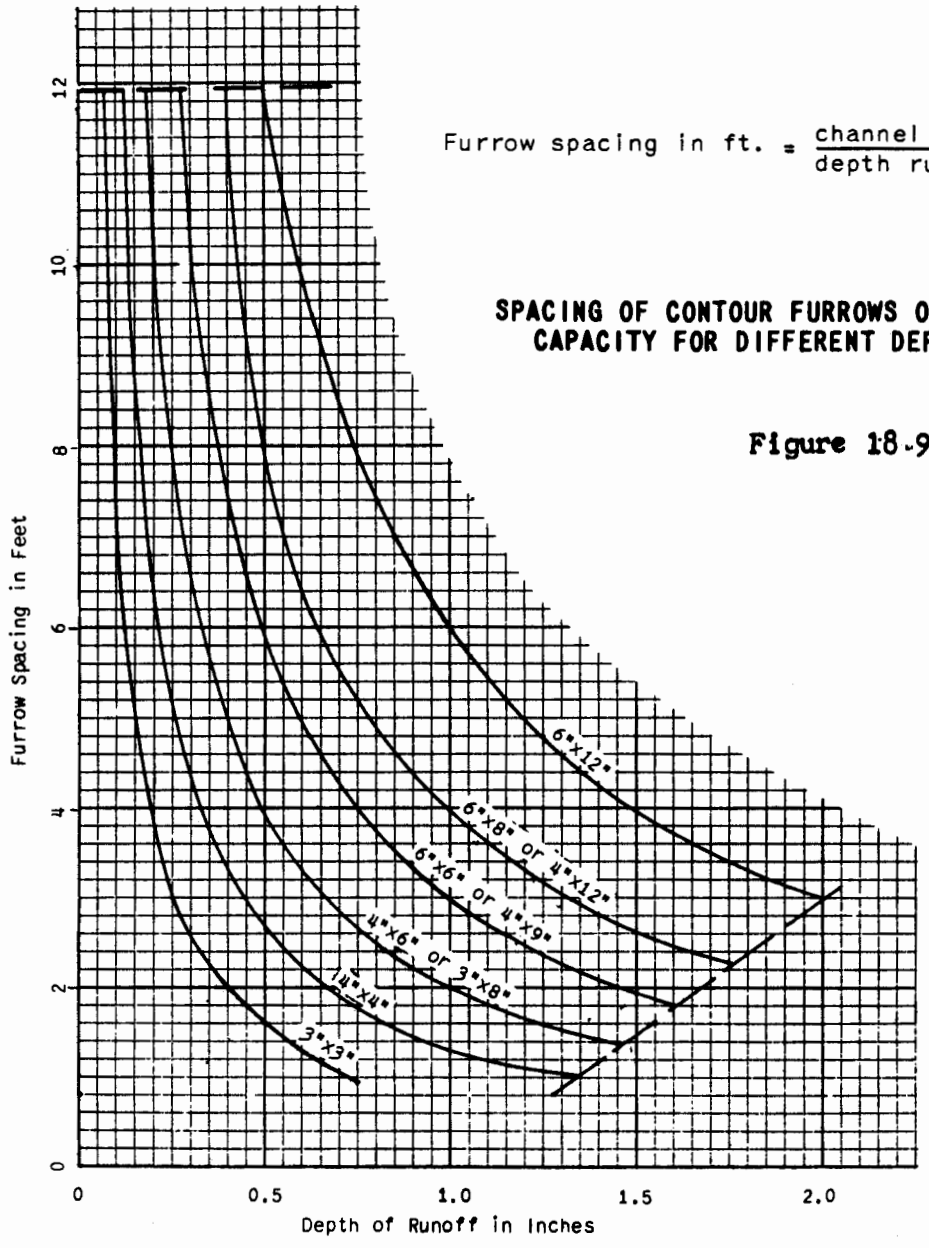
Runoff Producing Characteristics	40 Extreme	30 High	20 Normal	10 Low
Relief	(8) Steep, rugged terrain, with average slopes generally above 30%	(12) Hilly, with average slopes of 10 to 30%	(8) Rolling, with average slopes of 5 to 10%	(4) Relatively flat land, with average slopes of 0 to 5%
Soil infiltration	(8) No effective soil cover either rock or thin soil mantle of neglibible infiltration capacity	(6) Slow to take up water; clay or other soil or low infiltration capacity, such as heavy gumbo	(4) Normal; deep loam with infiltration about equal to that of typical prairie soil	(2) High; deep sand or other soil that takes up water readily and rapidly.
Vegetal cover	(8) No effective plant cover; bare or very sparse cover	(6) Poor to fair clean cultivated crops or poor natural cover; less than 10% of drainage area under good cover	(4) Fair to good; about 50% of drainage area in good grassland, woodland, or equivalent cover; not more than 50% of area in clean-cultivated crops	(2) Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover.
Surface	(6) Negligible; surface depressions few and shallow; drainageways steep and small; no ponds or marshes	(6) Low; well-defined system of small drainageways; no ponds or marshes	(4) Normal; considerable surface-depression storage; drainage system similar to that of typical prairie lands; lakes, ponds and marshes less than 2% of drainage area	(2) High surface-depression storage high; drainage system not sharply defined; large flood-plain storage or a large number of lakes, ponds or marshes

Figure 18.8

$$\text{Furrow spacing in ft.} = \frac{\text{channel x-sect. in sq. in.}}{\text{depth runoff in inches x 12}}$$

SPACING OF CONTOUR FURROWS OF VARYING CHANNEL CAPACITY FOR DIFFERENT DEPTHS OF RUNOFF

Figure 18-9



3. DESIGN FOR FURROWS (CONT'D)

SPACING OF CONTOUR FURROWS
2-Year Frequency

	Shelby Mont.	Miles City Mont.	Pierre S.Dak.	Wellington Kans.
Rainfall (In./Hr.)(From Fig. 18.6)	0.55"	0.75"	1.25"	1.75"
Assumed characteristics of Watershed (Figure 18.8)				
Relief - 8 Soil - 4 Cover - 6 (poor) Surface - 6 24 (Normal)				
Runoff coefficient - C (See Figure 18.7)	0.31	0.31	0.31	0.31
Runoff = Rainfall x C	0.17	0.23	0.39	0.54
Furrow spacing from Fig. 18.9				
3" x 3"	5.0'	3.3'	2.0'	1.5'
4" x 4"	7.6'	7.5'	3.4'	2.5'
4" x 6"	12.0'	8.6'	5.0'	3.6'
6" x 6"	12.0'	12.0'	7.6'	5.4'
4" x 12"	12.0'	12.0'	12.0'	7.2'
6" x 12"	12.0'	12.0'	10.8'	11.0'

Figure 18.10

3. DESIGN FOR FURROWS (CONT'D)

SPACING OF CONTOUR FURROWS
5-Year Frequency

	Shelby Mont.	Miles City Mont.	Pierre S.Dak.	Wellington Kans.
Rainfall (In./hr.)(From Fig. 18.6)	0.75"	1.10"	1.60"	2.25"
Assumed characteristics of Watershed (Figure 18.8) Relief - 8 Soil - 4 Cover - 6 (poor) Surface - 6 24 (Normal)				
Runoff coefficient - C (See Figure 18.7)	0.35	0.35	0.35	0.35
Runoff = Rainfall x C	0.26	0.39	0.56	0.79
Furrow Spacing from Fig. 18.9				
3" x 3"	3.0'	2.0'	1.4'	1.0'
4" x 4"	5.0'	3.4'	2.4'	1.7'
4" x 6"	7.6'	5.1'	3.5'	2.5'
6" x 6"	12.0'	7.6'	5.5'	3.8'
4" x 12"	12.0'	11.8'	7.0'	4.9'
6" x 12"	12.0'	12.0'	10.6'	7.5'

Figure 18.11

3. DESIGN FOR FURROWS (CONT'D)

Where contour furrowing is inadequate to prevent erosion on pasture areas that have excessive runoff, pasture terraces (as described in Part 4) should be used with contour furrows between them.

4. LAYOUT FOR FURROWS

Guide lines for contour furrows are level lines laid out on terrace intervals. After the guide lines are furrowed, the intervening areas are worked out in the same manner as contour farming a terraced area. Construct furrows halfway up and down from each guide line and stub furrow the odd, irregular areas halfway between the guide lines. The furrows should not cross drainageways, deep rills or roads as shown in Fig. 18.12.

5. CONSTRUCTION OF FURROWS

Cultivators and tool bar machines equipped with small shovels or chisel points, will make the smaller type of contour furrows. Small moldboard plows can be used on the larger furrows. The machine needs to be strong to withstand the speed and heavy pull in cutting sod. Rolling coulters ahead of the shovels or chisel may help in splitting the sod. Rolling coulters, however, are objectionable in that they delay the grassing over of the furrows where stoloniferous or rootstock grasses are present. Wings or drags behind the machine are needed to tousle the sod and waste it above and below the excavated furrow. A harrow might be used to break up the sod chunks after the furrows are constructed. The machine should be able to lift or lower the furrowing tools quickly so that the furrows stop short of rills, roads or drainageways, or provide blocks or dams.

Any season of the year is suitable for furrow construction if the ground is not too dry or frozen. The best construction time is in the spring and fall as pastures can be furrowed when cultivated fields are too wet to work and the vegetative growth is less.

Water Storage

If furrowing costs are considered comparable to plowing, the cost of water storage by this conservation practice is very reasonable. This is of great value when considering the storage potential from the standpoint of flood control and erosion control.

Proper management of grazing is essential to reduce rate of siltation and consequent loss of storage capacity. The effect of slope on storage capacity is minor with the narrower furrows on land as steep as 20% which is probably near the upper limit of slopes that can be furrowed.

The storage potential of contour furrows for any furrowed acreage and with any spacing and furrow size can be determined by the following formula:

$$V = \frac{w \times d \times A}{s}$$

5. CONSTRUCTION OF FURROWS (CONT'D)

Water Storage (cont'd)

where: d = depth of furrows in feet
V = volume in acre-feet
A = area furrowed in acres
w = width of furrows in feet
s = horizontal spacing of furrows in feet

For one acre of furrowing it can be seen that furrows 4 inches by 4 inches in size and spaced 4 feet apart will hold 1/36th of an acre-foot of water. Or, 1 acre-foot of water will be held on 36 acres. Furrows 4 inches by 4 inches by 3 feet apart will hold 1/27th of an acre-foot of water per acre, or 27 furrowed acres will hold 1 acre-foot of water.

Rainstorms of varying intensities and runoff may fill the storage potential more than once during the storm period if the stored water is able to infiltrate into the soil between the high intensity periods. For that reason the furrows may catch and store more than their storage potential during one storm period.

6. MAINTENANCE OF FURROWS

Proper management of grazing and adequate cover provide the best maintenance for contour furrows. If the furrows have silted full and have lost their effectiveness, a determination needs to be made as to whether the old furrows should be reshaped or new furrows constructed between the old ones. If the old furrows are supporting a better stand of grasses than there is between them, a new furrow should be constructed between the old ones.

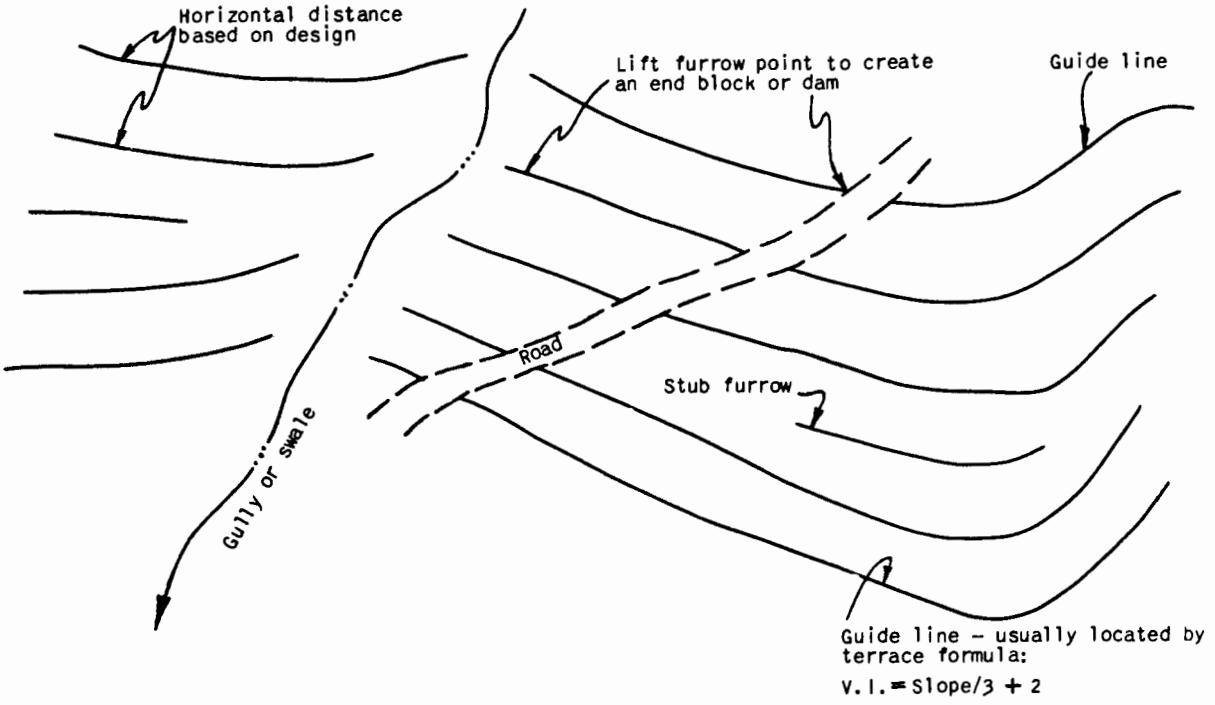
Maintenance of the furrows can be completed at two different seasons in one year, or over a two-year period, by reshaping alternate furrows. Small chunks of sod can be placed in furrows that are not level and are discharging water.

7. PITTING

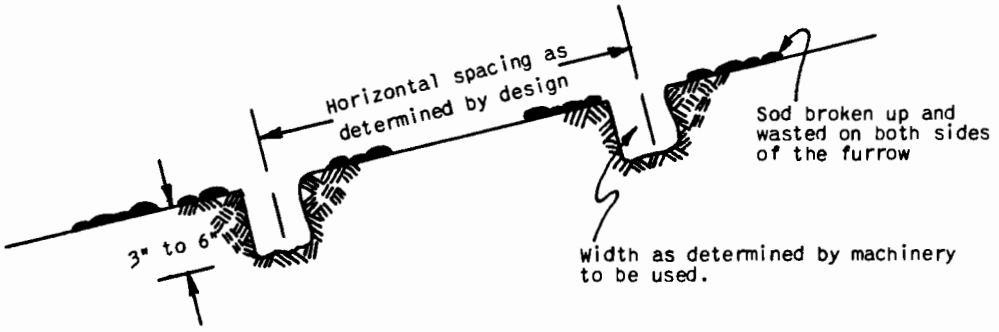
Pitting of pasture or range land with the eccentric disc creates a waffle-like surface by cutting out irregular-shaped strips of sod and moving it to one side. The excavations formed by the discs that have offset centers will store water and assist in water infiltration.

Areas suitable for pitting are similar to those suitable for furrowing yet furrows may hold more water on steep slopes while scattered woody plants interfere less in pitting operations.

"Runoff data from pitted pastures are given in Figure 18.3. Grazing and utilization records from shortgrass range for pitted and non-pitted range are given in reports issued by the Archer Experimental Station, Wyoming. Some of the conclusions reached by O. K. Barnes in Bulletin #318, Pitting and Other Treatments on Native Range are:


Horizontal distance based on design
Lift furrow point to create an end block or dam
Guide line
Road
Stub furrow
Gully or swale
Guide line - usually located by terrace formula:
V.I. = Slope/3 + 2

PASTURE FURROW LAYOUT


Horizontal spacing as determined by design
Sod broken up and wasted on both sides of the furrow
3" to 6"
Width as determined by machinery to be used.

PASTURE FURROW CROSS SECTION
No Scale

Figure 18.12

7. PITTING (CONT'D)

1. Pitting has been the most economical of all the successful treatments tested. Grooving at 2-foot intervals or similar treatments can be expected to accomplish similar results to pitting, but at higher cost.

2. Pitting serves to hold run-off during heavy rains. The actual holding capacity of the pits is about 1000 cubic feet per acre or the equivalent of 3/10's of an inch of rain. On some limited tests, pitting was found to increase the infiltration capacity of the range by over 50 percent.

3. **Pitting shortgrass range has increased grazing capacity about one-third and has resulted in average of 9 pounds more lamb per acre each year over the 10-year period. Even with the heavier stocking rate, pitting pastures had a 70 percent greater carryover of perenial grass than did the check pastures. On another and earlier group of treated pastures, pitted and grooving supported 22 percent more grazing and 6 and 8 pounds more lamb per acre, along with 30 and 50 percent more grass left at end of season.**

4. Ten years after pitting was installed, the pastures were still supporting more grazing, and the change in plant composition was persisting.

5. Field trials of pitting on different soils and vegetative types indicate that this treatment can be expected to improve any shortgrass type of range. The increase resulting from pitting may or may not be as great as the increase obtained in this study. Climatic conditions, application of the treatment, and other factors seem to influence plant response. In the field trials over the state, results indicate some sites with greater response than obtained in this study, and others with smaller increase. However, in no instance did pitting reduce forage production. Pitting on other range types failed to show any appreciable increase in forage production.

6. Pitting and seeding grass into the pits holds some promise as a reseeding method on sparsely covered sagebrush and desert sites. This operation applied to shortgrass range types failed to establish any appreciable amount of the introduced grass".

Level guide lines can be staked on regular terrace intervals, from which the pitter will work up half-way and down half-way. The irregular areas left between guide lines can be worked out the same as contour farming on cultivated fields, keeping the pits as level as possible to store the most water.

Some ranges can be renovated by mechanical treatment to catch and store water with simultaneous seeding of climax dominants. A seed box can be mounted on the pitter. Renovation of permanent tame, pastures is best accomplished by complete preparation of a seed bed and pasture planting. Pitting may then follow decline in rigor of the stand, usually with addition of fertilizer.

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CONTENTS

PART 20

CONCRETE

	Subject	Page
1.	General	20-1
2.	Principal Steps in Making Good Concrete Structures	20-2
	Selecting Ingredients	20-2
	Portland Cement	20-2
	Water	20-3
	Aggregates	20-4
	Proportioning	20-5
	Allowing for Moisture in the Aggregates	20-5
	Steps in Designing a Workable Mixture	20-6
	Air-Entraining Agents	20-7
	Mixing	20-8
	Importance of Mixing Ingredients Thoroughly	20-8
	Type of Mixer to Use	20-8
	Constructing and Bracing Forms	20-8
	Forms Should be Well Made	20-8
	Materials for Making Concrete Forms	20-8
	An Example	20-11
	Care in Using Forms	20-11
	Ready-Mixed Concrete	20-12
	Reinforcing Steel	20-13
	Placing	20-13
	Placing Concrete	20-13
	Transporting Concrete to Forms	20-14
	Placing Concrete Mixtures in Forms	20-14
	Joining New Work to Concrete Placed Previously	20-15
	Finishing	20-15
	Curing	20-16
	Necessity for Curing Concrete Properly	20-16
	Common Methods Used in Curing Concrete	20-16
	Hot Weather	20-17
	Cold Weather	20-17

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LIST OF FIGURES

PART 20

CONCRETE

Figure Number		Page
20.1	Maximum Size of Coarse Aggregates - - - - - - - - - - - -	20-4
20.2	Quantity of Water and Cement Per Batch for 1/2, 1/3, and 1/4 Bag Mixers - - - - - - - - - - - - - - - - - -	20-6
20.3	Spacing Data for Form Lumber and Form Ties - - - - - - -	20-9
20.4	An Example for Building Forms for Small Structures - -	20-10
20.5	Male Bolt Type Form and Spreader Tie - - - - - - - - -	20-10

PART 20

CONCRETE

1. GENERAL

Concrete is a mixture of aggregate, cement, and water. In properly made concrete each particle of aggregate, no matter how large or how small, is completely surrounded by paste and all spaces between aggregate particles are completely filled with paste. The aggregates are considered as inert materials while the cement and water paste is the cementing medium which binds the aggregate particles into a solid mass. Therefore, the quality of the concrete is greatly dependent on the quality of the paste and the paste must have the strength, durability, and resistance to the passage of water required by the job.

The cementing or binding properties of the paste are due to chemical reactions between the cement and water. These reactions require time and favorable temperature and moisture conditions. The reactions take place very rapidly at first and, under favorable conditions, continue more slowly for a long time. Although a relatively small amount of water is required to complete the chemical reactions, additional water is used for the sake of workability. With additional water, more aggregate can be used with resulting economy. As the paste is thinned with water, however, its quality is lowered; it has less strength and becomes less resistant to the elements. For successful results, then, a proper proportion of water to cement is essential.

The paste ordinarily constitutes 22 to 34 per cent of the total volume of concrete. The absolute volume of cement is usually between 7 and 14 per cent and the water from 15 to 20 per cent. Thus, 66 to 78 per cent of the concrete is made up of the aggregates. Since they constitute such a large part of the concrete, care in their selection is important. They should be graded to secure the best economy from the paste, they must be made up of particles having ample strength and resistance to exposure conditions, and they must not contain materials having injurious effects.

An important use of concrete is in structures that are expected to have long life and low upkeep. An essential requirement of such concrete is high resistance to these conditions of exposure. The most destructive of the natural forces of weathering is freezing and thawing action while concrete is wet or moist, and is due to the expansion of water as it is converted into ice. If the paste in the concrete is of high quality, that is, made with a small amount of water, it will be much more resistant than if a larger amount of mixing water is used.

To give maximum service and satisfaction, the concrete must be of good quality. Quality concrete is strong, durable, watertight, and possesses the other desirable characteristics of a construction material.

1. GENERAL (CONT'D)

It is just as easy to make concrete of good quality which gives excellent service as to make concrete of poor quality which may give disappointing service.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES

The making of good concrete structures involves:

1. Selecting ingredients
2. Proportioning
3. Mixing
4. Constructing and bracing forms
5. Cleanliness
6. Reinforcing steel
7. Placing concrete in forms
8. Finishing
9. Curing

Selecting Ingredients

The ingredients of concrete are portland cement, water, and sand-gravel aggregate.

Portland Cement. Portland cement is available from building material dealers and usually comes in paper sacks. Each sack contains 94 lbs. of cement, equal to one cubic foot in volume. Portland cement should be free-flowing powder when used. If it contains lumps that cannot be pulverized between thumb and finger, it should not be used. Portland cement should be stored in a dry place.

Normally Type I or Type II cement is used in small structures. There may be areas where it is necessary to use Type V portland cement.

Type I - Normal portland cement. This is a general purpose cement, suitable for all uses when the special properties of the other types are not required. It is used in reinforced concrete structures, tanks and reservoirs, culverts, water pipe, masonry units and for all uses of cement or concrete not subject to special sulfate hazard or where the heat generated by the hydration of the cement will not cause an objectionable rise in temperature.

Type II - Modified portland cement. This cement has a lower heat of hydration than Type I and generates heat at a slower rate. It also has improved resistance to sulfate attack. It is intended for use in structures of considerable size where cement of moderate heat and hardening will tend to minimize temperature rise, as in large piers, heavy abutments and heavy retaining walls when the concrete is placed in warm weather. In cold weather when the heat generated is of advantage, Type I cement

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Portland Cement (cont'd)

may be preferable for these uses. Type II cement is also intended for places where added precaution against sulfate attack is important, as in drainage structures where the sulfate concentrations are higher than normal but are not unusually severe.

Type V - Sulfate-resistant portland cement. This is a special cement intended for use only in structures exposed to severe sulfate action, such as in some areas having soils or waters of high alkali content. It has a slower rate of hardening than normal portland cement.

Air-entrained portland cement. Types I and II are available with very small quantities of certain air-entraining materials which are incorporated by intergrinding them with the clinker during manufacture. They are designated as Type IA and Type IIA. They have been developed to produce concrete resistant to severe frost action and to effects of applications of salt for snow and ice removal. Concrete made with these cements contains minute, well-distributed, and completely separated air bubbles. The bubbles are so minute it is estimated there are many billions of them in a cubic foot of the concrete. The entrained air is reflected in reduced weight of the fresh concrete. Best results are obtained when the air content is between 3 and 6 per cent. The reduction in weight will be not less than 3 lbs. per cubic foot nor more than 7-1/2 lbs. per cubic foot, since average concrete made without an air-entraining agent weighs about 150 lbs. per cubic foot and contains about 1 per cent air. The lower limit will give the required resistance to freezing and thawing under salt application but going beyond the upper limit is accompanied by an unnecessary reduction in strength without further improvement in durability.

Type IA or Type IIA (air-entrained cements) should be used.

Water. Mixing water should be clean and free from oil, alkali, or acid. In general, water that is fit to drink is suitable for mixing with cement. However, water with excessive quantities of sulfates should be avoided even though it may be fit to drink.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Aggregates. Sand-gravel should be clean and hard, free from dirt, oil, clay, and vegetable matter. Aggregates containing shales should not be used. These foreign materials are objectionable because they tend to prevent bond between the cement paste and aggregate, thereby resulting in low-strength concrete. Concrete made with dirty sand-gravel is likely to harden very slowly and often will not harden enough to serve its purpose.

Fine aggregate consists of sand or other suitable fine material. A good concrete sand will contain particles varying uniformly in size from very fine up to 1/4 inch. In well-graded sand the finer particles help fill the spaces between the larger particles. Good gradation of sand from coarse to fine is important for the workability of the concrete.

Coarse aggregate consists of gravel, crushed stone, or other suitable materials larger than 1/4 inch. Coarse aggregates that are sound, hard, and durable are best suited for making concrete. Those that are chemically reactive, soft, flaky, or wear away rapidly are unsatisfactory.

The maximum size of coarse aggregate depends on the kind of work for which the concrete is to be used. Coarse aggregate up to 1-1/2 inch in size, for example, may be used in a thick foundation wall or heavy footing. In walls, the largest pieces should never be more than 1/5 the thickness of the finished wall section. For slabs the maximum size should be approximately 1/3 the thickness of the slab. The largest pieces of aggregate should never be larger than 3/4 of the width of the narrowest space through which the concrete will be required to pass during placing. This is usually the space between the reinforcing bars or between the bars and the forms. Coarse aggregate is well-graded when particles range uniformly from 1/4 inch up to the largest size that may be used on the kind of work to be done.

The following are the maximum sizes of aggregates recommended:

Thickness of Concrete Walls	Size of Aggregates	Thickness of Concrete Slabs	Size of Aggregates
4"	7/8"	2"	5/8"
5"	1"	2-1/2"	3/4"
6"	1-1/8"	3"	1"
7"	1-3/8"	3-1/2"	1-1/4"
8" and over	1-1/2"	4"	1-3/8"
		4-1/2" and over	1-1/2"

Figure 20.1 Maximum Size of Coarse Aggregates

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Aggregates (cont'd)

Bank-run (dry pit) sand-gravel is quite likely to contain foreign materials and vegetable matter and should not be used without testing unless it is known that good concrete can be made from this material. If there is any doubt about the cleanness of the bank-run material, a sample test known as the silt test can be made to determine its suitability. It is made as follows:

(1) Fill a fruit jar to a depth of 2 inches with a representative sample of the bank-run material.
(2) Add water until jar is about 3/4 full.
(3) Shake vigorously for a minute or two--the last few shakes in a direction to level the material.
(4) Allow the mixture to stand for about 1 hour; the silt will settle in a layer on top.
(5) Measure the depth of the silt layer.

If the silt layer is 1/8 inch or more in depth, the aggregate is unsuitable for making concrete. Washed aggregates can usually be purchased from material dealers. It pays to buy aggregates known to make good concrete.

Proportioning

Strength, durability, and watertightness of concrete are controlled by the amount of water used per sack of cement. In general, the less water used the better the quality of the concrete, as long as the mixture is plastic and workable. Some concrete jobs must be stronger and more watertight than others; less water is used for such concrete.

Allowing for Moisture in the Aggregates. Most sand-gravel aggregate contains some water. Therefore, allowance must be made for this moisture in determining the amount of water to add to the mix. Otherwise the mixes will contain more than the correct amount of water to get the quality of concrete desired. A simple test for determining whether clean or washed aggregate is damp, wet, or very wet is to press some together in your hand. If it falls apart when your hand is opened, it is damp; if it forms a ball which holds its shape, it is wet; if the sand-gravel sparkles and wets your hand, it is very wet.

The amount of water to add when sand-gravel is dry, damp, wet, or very wet for various kinds of work is shown in Figure 20.2. In cases where sand and gravel are separate and batched by weight rather than volume, sufficient extra sand must be added to compensate for the moisture.

Most mixers used on small jobs do not hold a full one-sack batch. It is necessary then to use 1/2, 1/3, 1/4, or some other fraction of

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Allowing for Moisture in the Aggregates (cont'd)

a sack per batch. It is very important to control the proportions of water and cement in mixing concrete. This may be done by using the following proportions of water and cement for the particular size mixer and the moisture content of the sand and gravel:

Design Mix Water Per Sack, Gal.	Cement Per Batch, Lb.	Quantity of Water to Add in Quarts When Sand-Gravel is			
		Dry	Damp (average)	Wet	Very Wet
		1/2-bag mixer			
5	47	10	8-1/4	6-1/2	4-3/4
6	47	12	10	8	6
		1/3-bag mixer			
5	31-1/3	6-2/3	5-1/2	4-1/3	3-1/6
6	31-1/3	8	6-2/3	5-1/3	4
		1/4-bag mixer			
5	23-1/2	5	4-1/8	3-1/4	2-3/8
6	23-1/2	6	5	4	3

Figure 20.2 Quantity of Water and Cement Per Batch for 1/2, 1/3, and 1/4 Bag Mixers

For a 1/2-bag mixer with damp sand-gravel 10 qts. of water and 47 lbs. of cement are to be used to maintain the proportion of 6 gals. of water per sack of cement. Separate pails used for measuring water and cement are marked at the proper height when the first batch is made. All succeeding batches are made by filling the pails with water and cement to the marked levels. The proportion of water to cement is very important in securing quality concrete.

Steps in Designing a Workable Mixture. A workable mix is one that is smooth and plastic and that will place and finish well. It should not be so thin that it runs or so stiff that it crumbles. It should be rather sticky when worked with a shovel or trowel. For most work a workable mix is one which is "mushy" but not "soupy."

The first step is to determine the correct amount of water to use per sack of cement (5 to 6 total gallons of water per sack of cement)

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Steps in Designing a Workable Mixture (cont'd)

to produce a concrete that will withstand the weathering elements and service to which the concrete will be subjected in use. Care should be taken not to change this proportion as it controls the strength, durability, watertightness, and other desirable qualities of the concrete.

One suggested mix for good concrete is as follows: One sack of portland cement (1 cu. ft.) to 2 cu. ft. of sand to 3-1/2 cu. ft. of gravel and the maximum of 6 gallons of water. Change proportions of aggregate slightly if necessary to get a workable mix.

Air-Entraining Agents. Air-entraining admixtures used in concrete will improve the workability and durability, and in the case of exposed slabs will produce a concrete resistant to severe frost action.

Properly proportioned air-entrained concrete contains less water per cubic yard than non-air-entrained concrete of the same slump and has better workability. This results in a more solid, weather-resistant, blemish-free surface. It can be handled and placed with less segregation of materials, and it has less tendency to bleed (water gain at the top of concrete due to settlement of solids prior to initial set).

These properties indirectly aid in promoting durability by increasing the uniformity of the concrete.

When using air-entrained cements or admixtures containing air-entraining agents, care must be taken that the quantity of water in the concrete mix is adjusted to maintain the desired slump. Such mix design and adjustments should be made only by a qualified engineer or concrete technician.

Because of its proven service record, both in the laboratory and field, and because of its increased workability and durability, air-entrained concrete is strongly recommended for all concrete, regardless of exposure conditions. Where concrete will be subjected to freezing and thawing, its use should be required. Close control must be maintained as excessive air entrainment will reduce the strength of concrete. The following percentages of air entrainment are recommended:

Maximum Size Aggregate	Entrained Air
3/4 in.	5 to 7 per cent
1-1/2 in.	4 to 6 per cent

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Air-Entraining Agents (cont'd)

Unless a person has had experience with their use, accelerators, retarders, or antifreeze compounds should not be used; therefore, they are not recommended for general use.

Mixing

Importance of Mixing Ingredients Thoroughly. Cement paste (cement and water) is the cementing material which upon hardening binds the aggregate particles together and gives concrete its strength, durability, and watertightness. Continue mixing for at least 1 minute and preferably up to 3 minutes after all materials have been placed in the mixer. Well-mixed concrete will have a uniform color.

Type of Mixer to Use. A machine mixer of the drum type is best. It should be run at a speed slow enough to allow time for the materials to fall away from the top of the drum as it revolves. Avoid overloading the mixer, for this prevents proper mixing action. If the mixer is of the barrel type, adjust it to run in as nearly a horizontal position as possible without spilling water during mixing.

Constructing and Bracing Forms

Forms Should be Well Made. Forms must be substantial enough to retain their correct shape when filled, for freshly mixed concrete exerts great pressure. It is not enough that forms be strong, they must also be rigid. Disappointment will result if one finds after concrete is placed that the forms are bulged. If the forms are not tight, the escape of the water-cement paste from small openings may result in honeycombing or a loss of water which may cause sand streaking.

Forms should be constructed so they can be easily filled and easily removed after the concrete has hardened. Double-headed nails or screws which can be withdrawn readily will assist greatly in removing forms without damaging the new concrete.

Materials for Making Concrete Forms. Wood and metal materials are suitable for concrete forms.

Lumber used for forms should be sound and free from knotholes and decay. Concrete-form-grade plywood makes excellent forms. Sheathing lumber, dressed on at least one side and both edges, is also recommended. Where smooth, true surfaces are required, it is best to use lumber that is dressed on all four sides. Tight joints are obtained by using tongue and groove stock or shiplap. Use lumber of commercial length and widths that will be most suitable.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Materials for Making Concrete Forms (cont'd)

The sketch shown in Figure 20.4 shows an example of a method for building forms for a small structure. By following the information in Figure 20.3, the proper spacing for studs, wales, and form ties can be determined. The example gives the procedure for the use of the table in Figure 20.3

50°					Minimum Setting Temperature					70°
2'	3'	4'	5'	6'	Rate of Fill Per Hour	2'	3'	4'	5'	6'
450#	600#	750#	900#	1050#	Maximum Pressure Per Sq. Ft.	350#	450#	550#	650#	750#

Spacing of Studs for Safe Value of Sheathing

22"	20"	18"	16"	15"	Spacing for 3/4 Sheathing	24"	22"	20"	18"	16"
41"	36"	32"	30"	28"	Spacing for 1-5/8 Sheathing	44"	41"	39"	37"	32"

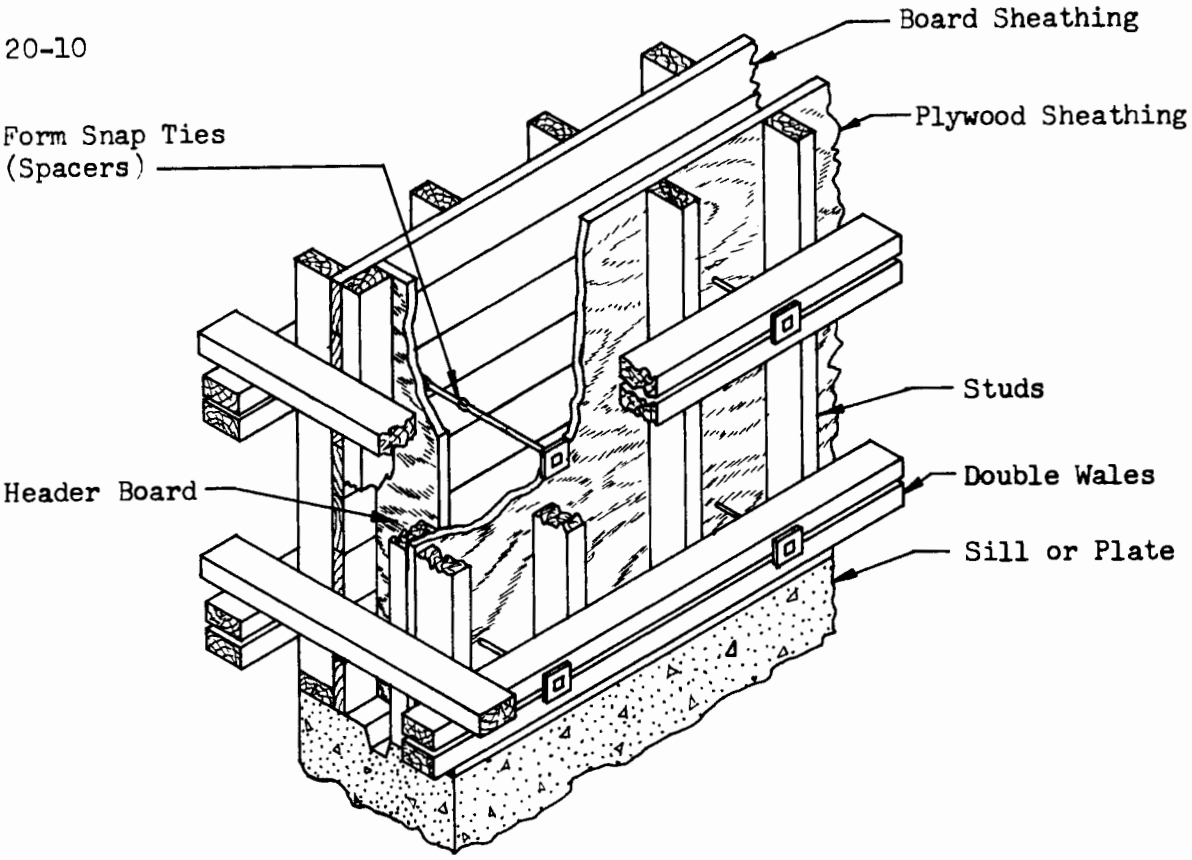
Spacing of Wales for Safe Value of Studs

30"	28"	26"	25"	24"	2X4 Studs and 3/4 Sheathing	33"	30"	29"	28"	26"
47"	43"	40"	39"	37"	2X6 " " " "	51"	47"	45"	44"	40"
34"	32"	30"	29"	27"	2X6 " " 1-5/8 "	38"	34"	32"	31"	30"

Spacing of Ties for Safe Value of Wales

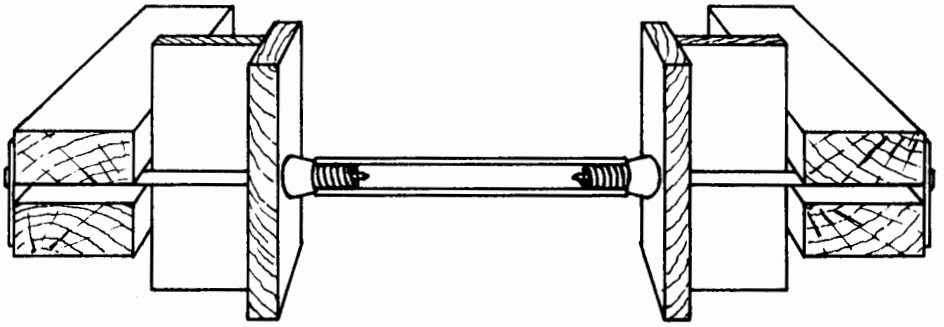
33"	29"	27"	25"	24"	Dble 2X4 Wale 2X4 Stud 3/4S	36"	33"	30"	28"	27"
26"	23"	22"	20"	19"	" 2X4 " 2X6 " "	29"	26"	24"	23"	22"
51"	46"	42"	40"	37"	" 2X6 " 2X4 " "	56"	51"	47"	44"	42"
40"	37"	34"	32"	30"	" 2X6 " 2X6 " "	45"	40"	38"	36"	34"
48"	43"	40"	37"	35"	" 2X6 " 2X6 " 1-5/8S	52"	48"	45"	42"	40"

Figure 20.3 Spacing Data for Form Lumber and Form Ties

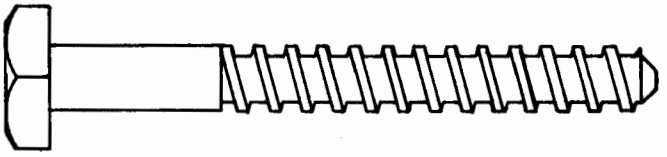


AN EXAMPLE FOR BUILDING FORMS FOR SMALL STRUCTURES

Figure 20.4



MALE BOLT TYPE FORM AND SPREADER TIE



MALE BOLT

Figure 20.5

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

An Example

Problem

Determine the proper spacing of the studs, wales, ties, and the unit load per tie where the following conditions are known:

1. Sheathing - 3/4", studs - 2X4, wales--double 2X4.
2. Rate of pour 4 feet per hour.
3. Setting temperature of concrete--70°.

Solution

To the right in Figure 20.3, the table is based on a setting temperature of 70° (meeting condition 3). In the table, columns are given for rates of pour varying from 2' to 6'. We are only concerned with the rate of 4 feet per hour, and the third column shows the correct spacing of the studs, wales, and ties at this rate. Thus by reading down this column under the heading "Spacing of Studs" and opposite "spacing for 3/4" sheathing," the spacing of the studs is 20"; continuing under the heading "Spacing of Wales" and opposite "2X4 studs, 3/4" sheathing," the spacing of the wales is 29"; and under "Spacing of Ties," opposite "Double 2X4 wales, 2X4 studs, 3/4" sheathing," the spacing of the ties is 30".

The total load per tie is obtained by multiplying the maximum pressure per square foot (550 lbs.) found at the top of the column by the area supported by the tie. [Spacing of the wales 29" (2.42'), times the spacing of the ties 30" (2.5')]. Thus 550 lbs. x 2.42 x 2.5 = 3,327.5.

Should the recommended working load of the tie selected be under 3,000 lbs., the spacing between the ties is decreased accordingly. This is determined by dividing the working load of the tie by the product of maximum pressure per sq. ft. (in this case 550 lbs.) and wale spacing expressed in feet. Thus, if a 3,000 lb. tie is used, the proper spacing is 3,000 ÷ (550 x 2.42') = 2.25' (26").

This simple problem with its corresponding solution illustrates the proper use of the tables.

Care in Using Forms. To prevent concrete from sticking to the forms and to make form removal easy, it is customary to oil form faces which come in contact with concrete. A light, clear lubricating oil is suitable. Commercial form oil is available from most suppliers. For easy brushing, the oil should be cut with about an equal amount of kerosene. Forms should be cleaned and oiled each time they are used. Dry, untreated wood forms will absorb water from the concrete, often leaving the concrete surface too dry for best results. Forms may warp badly unless oiled.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Care in Using Forms (cont'd)

To hold opposite form faces of walls the correct distance apart, best results are obtained by using spreader ties. Many form ties on the market today are usable as a combination spreader and form tie. One style is manufactured so that it may be twisted or broken off in the concrete about 1 inch back of the surface. Another style is the male bolt system shown in Figure 20.5. In this type of form tie an anchor is left embedded in the concrete, but the special self-cleaning bolt is salvaged for re-use. Wire ties should not be used. Holes are patched by forcing in a wet mortar made with the same proportions as the sand and cement as was used in the concrete. To prevent patched areas from appearing darker than the wall, from 1/4 to 1/2 the cement used in patching should be white portland cement.

In summer, wall forms generally can be stripped (removed) after 1 or 2 days and in cold weather in 4 to 7 days. Forms must never be removed until it is certain that the concrete has hardened enough to be self-sustaining.

Ready-Mixed Concrete. In many areas ready-mixed concrete may be purchased from a central plant. In some instances the concrete is mixed completely in a stationary mixer and the mixed concrete is transported to the job in agitator trucks or transit mixer trucks operated at agitator speed.

In some ready-mixed operations the materials are dry batched at the central plant and then mixed enroute to the job in truck mixers. In another procedure, referred to as shrink-mixing, the concrete is mixed in a stationary mixer at the central plant only sufficiently to intermingle the ingredients, generally about 1/2 minute. The mixing is then completed in a truck mixer enroute to the job.

Truck mixers consist essentially of a mixer with separate water tank and water-measuring device mounted on a truck chassis. They are usually made with capacities of 1, 1-1/2, 2, 3, 4, and 5 cu. yd. Agitator trucks are similar but without provisions for water.

When a truck mixer is used either for complete mixing or to finish the partial mixing, each batch of concrete is to be mixed not less than 50 nor more than 100 revolutions of the drum or blades at the rate of rotation designated by the manufacturer as mixing speed. Any additional agitating for mixing is to be done at the speed designated by the manufacturer as agitating speed. The concrete must be delivered and discharged from the truck mixer or agitator truck within 1-1/2 hours after introduction of the water to the cement and aggregate or the cement to the aggregate. Prolonged or excessive mixing will generate heat to increase the temperature of the concrete mix. In warm weather the concrete mix temperature should be maintained in the

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Ready-Mixed Concrete (cont'd)

70° to 80° F. range so far as practical. This may be accomplished by (1) using cold mixing water or ice, (2) keeping materials as cold as practicable by shading or spraying aggregate piles to provide evaporation cooling, (3) painting mixing drums white and keeping them white.

Reinforcing Steel

Placing. Before any concrete is placed, the reinforcement should be checked for size, bending, spacing, location, firmness of installation, and surface condition. Before reinforcement is placed, the surface should be free from objectionable coatings, particularly heavy corrosion caused by out-of-door storage. A thin adherent film of rust or mill scale is not considered to be seriously objectionable. Loose rust or scale, which can be removed by rubbing with burlap or by other effective means, should be removed. Other objectionable coatings likely to be found on parts of the reinforcement are paint, oil, grease, dried mud, and weak dried mortar which has been splashed on the bars ahead of concrete being placed.

Reinforcement should be properly spaced, spliced and anchored, embedded a minimum distance from the surface; and accurately located and firmly held. Except where shown on the plans, no splices of reinforcement should be made without the approval of the engineer. At splices the bars should be lapped 30 diameters to transfer the stress by bond and shear. All the steel reinforcement should be accurately located in the forms and firmly held in place before and during the placing of concrete by means of small concrete blocks, spacer bars, wires, or other devices adequate to insure against displacement during construction and to keep the steel at the proper distance from the forms. The use of rocks, wood blocks, or other unapproved objects to support the steel should not be permitted. In general, horizontal bars should be supported at intervals not to exceed 5 or 6 feet. Small precast concrete blocks make excellent supports especially with wire ties embedded. Wire used in tying bars should not be smaller than 18 gage. Where wire ties are used, the twisted ends should be made to project away from the exterior surface. Steel may be spot-welded in lieu of tying.

During the concreting the reinforcement, especially the light "temperature steel," is likely to become displaced. Constant attention is required to detect and correct any displacement of reinforcement.

Placing Concrete

The concrete mixture should be placed in the forms just as soon as possible and not longer than 1-1/2 hours after mixing.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Transporting Concrete to Forms. On small jobs wheelbarrows are the usual means of transportation. On larger jobs buggies and chutes are commonly used. Whatever method is used, care should be taken to prevent segregation or separation of coarse from fine particles. Such separation is likely to occur when concrete is transported over rough ground or runways. Avoid "sloppy" mixtures because they segregate badly.

Placing Concrete Mixtures in Forms. All foreign material, such as chips, blocks, sawdust, dried mortar, and dirt, shall be removed from within the forms. In deep, narrow forms it may be necessary to have inspection openings so that any foreign material can be readily removed. Doors to close these openings should be built before concreting operations are started.

The concrete should not be allowed to drop freely more than 4 or 5 feet. In thin sections, drop chutes of rubber or metal should be used. In narrow wall forms the metal drop chutes may be made rectangular to fit between reinforcing steel.

Concrete is sometimes placed through openings, popularly referred to as "windows," in the sides of tall, narrow forms. When a chute discharges directly through the opening, there is danger of segregation. An outside pocket permits the concrete to flow through the opening and there is much less tendency to segregate. In high walls, 10 feet or more, the concrete should be placed to a point about 1 foot below the top and an hour or so allowed for settling. Concreting should be resumed before set occurs to avoid a joint.

Deposit the concrete in level layers not more than 12 inches deep at one time, tamping and spading just enough to make it settle thoroughly and produce a dense mass. Working the concrete next to the forms insures an even, dense surface when forms are removed.

Internal mechanical vibrators may be used within the concrete. This process should eliminate pockets and large bubbles of air, consolidate each layer with that previously placed, completely embed reinforcing and fixtures, and bring just enough fine material to the faces and top surfaces to produce the proper finish. Vibration itself does not make concrete stronger, more watertight, or more resistant to deteriorating forces. It does permit the use of stiffer, harsher mixes; thus, either mixes of lower water content or leaner mixes for a given water content can be used. If less water is used, the concrete will be of better quality; if leaner mixes are used, the concrete will be more economical.

It is just as important to prevent segregation in the forms as it is when transporting the concrete from the mixer to the forms. Depositing the concrete uniformly within the forms where it is to be used rather than placing it at a few points and dragging it or causing it to flow where needed helps prevent segregation and honeycombing.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Placing Concrete Mixtures in Forms (cont'd)

Further care is required to see that the material is properly worked into the corners and angles of forms and, in reinforced work, around reinforcement.

If the mixture becomes sloppy as the forms are filled, use a stiffer mixture. The consistency should be changed by adjusting the amounts of coarse and fine aggregate, not the water.

Joining New Work to Concrete Placed Previously. At the end of the day's run or where the work must be stopped long enough for the concrete to begin hardening, roughen the top surface just before it hardens to provide a good bond for the next layer of concrete. Just before resuming the placing of concrete, clean the roughened surface and then brush it with a cement-water paste of thick, creamy consistency. Apply this paste in a thick brush coat just ahead of the concrete operation so that it does not have a chance to dry before it is covered with concrete. In deep forms it may be necessary to drop the paste on the joint. This precaution to get a good bond between different layers of concrete is very important wherever the concrete construction is to be watertight.

Finishing

To finish the fresh concrete, it is struck off flush with the top of the forms as soon as it is placed; then the wood float is used to make an even surface. The newer magnesium float produces a superior finish for finishing air-entrained concrete.

The final finishing is delayed until the concrete hardens enough to become quite stiff; then finishing with a wood float results in a uniform gritty surface.

Surface water should be avoided. However, when a small amount is present, it should be allowed to evaporate before finishing. If there is considerable water, it is removed with a broom, belt, float, or other convenient means. It is never good practice to sprinkle dry cement or a mixture of cement and fine aggregate on fresh concrete to take up surface water; such fine materials form a layer on the surface that is likely to dust or hair check when the concrete hardens.

For a smooth finish follow the wood float with a steel trowel after the surface has become quite stiff. Excessive troweling or the use of the steel trowel before the mix has become stiff is likely to produce surfaces that dust or develop fine cracks. Use the steel trowel sparingly.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Curing

Necessity for Curing Concrete Properly. Proper curing of concrete increases its strength, durability, and watertightness.

Concrete hardens because of chemical reaction between portland cement and water. Hardening continues as long as temperatures are favorable and moisture is present to hydrate the cement.

Moist curing greatly increases the strength of concrete. Concrete damp-cured for 7 days will be approximately 50 per cent stronger than similar concrete which is permitted to dry out. Concrete damp-cured for 1 month will be approximately 100 per cent stronger than similar concrete exposed to dry air. The strength of damp-cured concrete is influenced by the length of time the concrete is kept damp. It also hardens faster at higher temperatures. Concrete cured at 70° F. generally hardens more than twice as fast as concrete cured at a temperature slightly above freezing.

Thorough moist-curing aids in producing watertight concrete. As the cement paste in concrete hardens, additional solid matter is formed. This paste closes off the space between the cement particles through which water might otherwise seep. The more complete the hydration or the hardening process, the denser and more watertight becomes the cement paste.

Increased resistance to wear also results from proper curing. This emphasizes the importance of damp-curing surfaces subject to wear. Continuous damp-curing, particularly in the early stages of hardening, helps to get a hard, dense surface and reduces checking and dusting.

Common Methods Used in Curing Concrete. The concrete should be covered with wet burlap, canvas, sand, or straw as soon as it can be done without marring the surface. Keep the covering continuously wet by sprinkling. When a cover is not used, wetting should be started as soon as possible after finishing, and the surface should not be permitted to dry during the curing period. Alternate cycles of wetting and drying of green concrete is conducive to crazing or cracking of the surface. Flat surfaces require careful attention since the relatively large exposed surface loses moisture very rapidly by evaporation. Ponding (flooding) is a good method of curing flat surfaces. The surface to be cured is surrounded by small earth dikes and then kept flooded with water.

Walls and other vertical surfaces can be protected by leaving the forms in place temporarily, or by hanging canvas or burlap over them. Such coverings should be kept constantly moist by

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Common Methods Used in Curing Concrete (cont'd)

sprinkling. Curing should continue for at least 7 days, and for longer periods of time when it is practical to do so.

If sealing curing compounds are used, they should be of black or white pigmented coatings. By using colored curing compounds, it is much easier to see how complete a coverage of the concrete surface is being obtained. It is very important to have complete coverage to prevent the escape of water that is in the fresh concrete. Some of them are applied in one coat, but two coats will give better results. The application should be made immediately after the concrete has been finished. If there is any delay, the concrete should be kept moist until the application is made. On formed surfaces, the forms should be removed, the concrete sprayed lightly with water, and then the sealing compound applied.

Hot Weather. In extremely hot weather certain precautions should be taken to avoid high temperatures in the fresh concrete. High temperatures cause rapid stiffening. They also increase the danger of the hardened concrete cracking due to thermal contraction upon cooling.

Keeping aggregate stockpiles moistened with cool water will assist in lowering the temperature. Ice may be added to the mixing water.

Subgrades on which concrete is to be placed should be saturated some time in advance and then sprinkled just ahead of the placing operation. Wood forms should be thoroughly wetted if they have not been otherwise treated. The fresh concrete should be shaded as soon as possible after finishing and moist curing should be started early--as quickly as it can be done without marring the surface. In some extreme instances, placing of concrete is discontinued during the hottest part of the day. Attention to curing is even more important than under normal conditions to avoid rapid drying.

Cold Weather. In cold weather construction it is often necessary to heat the materials and to cover the fresh concrete or to provide a heated enclosure. The hydration of the cement causes some heat to be generated; if this heat is retained, it raises the temperature of the concrete. The effect of this heat depends largely on the shape and size of the structure. In large members the heat will be retained longer than in small structures. It is difficult, therefore, to set down hard and fast guides to cover all cases. Usually, in cold weather, the concrete in ordinary reinforced concrete structures should be placed at a temperature of approximately 70° F. In no case should be materials be heated to the point that the temperature of the fresh concrete is above 80° F. Excessive heating lowers the strength of the concrete.

2. PRINCIPAL STEPS IN MAKING GOOD CONCRETE STRUCTURES (CONT'D)

Cold Weather (cont'd)

In relatively mild weather, that is, when the temperature is generally above 40° to 45° F. with only short periods below this range, heating only the mixing water usually will be sufficient to provide the desired temperature in the concrete. More heat units can be stored in the water than in the other materials and it is also the most convenient material to heat.

After concrete is in place, it should be kept at a favorable temperature long enough to avoid injury by exposure to the atmospheric temperature. In general, the air surrounding the concrete should be maintained at or above 50° for the first 5 days after placing for normal concrete, or at or above 50° for 3 days when high-early-strength concrete is used. These are minimum requirements as far as exposure to low temperatures is concerned. Where damp-curing is required, protection against low temperatures must be extended for the full curing period.

In mild weather a covering of tarpaulins may be enough protection. A layer of straw covered with tarpaulins will protect against more severe conditions, but an enclosure of tarpaulins or other weather tight material with artificial heat is necessary to provide proper protection in many cases. Unit heaters or oil-burning salamanders are used for heating. The enclosure must be constructed so that air can circulate outside the outer edges and members. Heating elements must be placed so that these outside members are protected. Precautions are necessary to prevent rapid drying of the concrete, especially near the heating elements. If necessary, these elements should be elevated and the concrete near them protected with sand kept constantly wet.

Concrete should not be placed on a frozen subgrade. When such a subgrade thaws, there is likely to be uneven settlement and cracking of the concrete member it supports. The insides of forms, reinforcing steel and embedded fixtures should be free of ice at the time concrete is placed. A thin layer of warm concrete should not be placed on cold, hardened concrete for the thin upper layer will shrink as it cools and the lower layer will expand as it warms; bond failure will result. The temperature of the fresh concrete should be as near that of the hardened concrete as possible. This may require warming of the hardened concrete.

Too rapid cooling of the concrete at the end of the protection period should be avoided. Sudden cooling of the surface while the interior is still warm may cause stress sufficient to crack the concrete. Cooling at the rate of about 20° in 24 hours is satisfactory. Gradual cooling can be accomplished by shutting off the heat and allowing the enclosure to cool to approximately outside temperature before the coverings are removed.